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THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

Edited by

GEORGE E. HALE
Mount Wilson Observatory of the Carnegie Institution of Washington

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THE SPECTRUM OF THE SOLAR CORONA

By IRA M. FREEMAN

ABSTRACT

It has been found possible to *associate over half* of the "unknown" emission lines of the *corona*, with known lines in the *spectrum of argon*, from the data compiled by Campbell and Moore. *Ten more* coronal wave-numbers were given by *intercombinations* of Meissner's term values for argon.

A systematic examination of the spectra of prominent solar elements gave *no significant correlations* beyond a few chance numerical agreements.

The *means of excitation* of the coronal lines is discussed, and the bearing of the present identification on modern theories of the *physical nature* of the corona is indicated.

The greater part of our information concerning astronomical bodies is brought to us by the light they radiate or reflect. In most instances the radiation from distant bodies reveals the presence of familiar terrestrial chemical substances; but there are a few classes of celestial spectra which for a long time have remained unrecognized as pertaining to any known earthly materials. There are lines of unknown origin in the spectra of the nebulae, the solar corona, the Wolf-Rayet stars (O type in the Draper Classification), and the novae, or "new" stars. Besides these spectra, with "unknown" lines we have on record uninterpreted bands in cometary spectra, and in the spectra of several planets.

An interesting attempt at an explanation of the origin of the spectra with unknown lines was made by J. W. Nicholson in a series of papers which appeared in the *Monthly Notices of the Royal Astronomical Society* almost two decades ago.[1] But Nicholson's scheme

[1] *Monthly Notices, Royal Astronomical Society*, **72**, 49, 139, 677, 729, 1911; **74**, 118, 204, 425, 486, 623, 1913.

involved a type of atomic model very different from the highly successful Rutherford model, and today his theory has little more than historical interest.

An explanation of the source of the nebular lines, fitting more readily into our present theories of spectra and atomic structure, has been offered recently by I. S. Bowen. Utilizing the clue that regular nitrogen lines are known in nebular spectra, he was able to classify eight of the stronger of the unknown lines as transitions from metastable states of singly ionized nitrogen and singly and doubly ionized atoms of oxygen; and several of the weaker lines probably result from metastable transitions in more highly ionized atoms of these same substances.[1] The predictions fit well with our present knowledge of the spectra of highly ionized atoms obtained from terrestrial sources (vacuum spark), and with the probable conditions of temperature and pressure in the nebular bodies.

In the problem of cometary spectra, Fowler showed[2] that the bands occurring in the tails of certain comets, notably Daniels (*d* 1907) and Morehouse (*c* 1908), can be reproduced in the laboratory under low pressures (0.01 mm) of carbon compounds. Further work by a number of investigators[3] developed improved methods of excitation, and indicated that CO^+ was the emitter of the bands.

There are several bright bands in the *heads* of a few comets—for instance in Comet Wells and in Comet Brooks—which at present remain unidentified.[4]

The spectra of the Wolf-Rayet stars, of the novae, and of the planets are still without adequate explanation, but the opinions of leading workers in celestial spectroscopy appear to concur in the surmise that the remaining unknown spectra will be linked, ultimately, to radiations from familiar substances.[5]

The solar corona is a misty, highly attenuated, pearl-gray aura enveloping the sun, extending irregularly as much as ten million

[1] *Astrophysical Journal*, **67**, 1, 1928.

[2] *Monthly Notices, Royal Astronomical Society*, **70**, 176, 1909; 484, 1910.

[3] Merton and Johnson, *Proceedings Royal Society*, **103A**, 383, 1923; Lemon, *Proceedings National Academy of Sciences*, **11**, 41, 1925; Blackburn, *ibid.*, **11**, 28, 1925; Baldet, *Comptes Rendus*, **180**, 1201, 1925.

[4] F. J. M. Stratton, *Astronomical Physics*, p. 65, 1925.

[5] See for example Russell, Dugan, and Stewart, *Astronomy*, p. 837, 1927.

miles from the solar surface, and visible only at the time of total solar eclipse. It has a general radial filamentary structure, and the extent and form undergo variations in phase with the sun-spot cycle.[1]

Spectrograms reveal three types of radiation: a continuous emission spectrum, a very faint Fraunhofer spectrum, and a group of some forty-five unknown emission lines. The continuous spectrum seems to be due almost entirely to sunlight scattered by the material of the corona, and it is almost certainly established that the Fraunhofer spectrum here observed is that of the sun, reflected by the corona.

The striking mystery of the origin of the bright lines was recognized from the earliest spectroscopic observations of the corona made about sixty years ago. The curious fact that no familiar element discloses its presence in the spectrum of the corona itself makes the situation all the more perplexing. In the early records, the presence of the lines of hydrogen and of calcium was interpreted to mean that these elements were present in the corona, but it is now known definitely that these lines come from the flaming prominences which extend up into the coronal envelope.

Before refined methods were developed, certain of the unknown lines were confused with lines from well-known spectra occurring in the sun itself. In fact, the brightest coronal line was once suspected to be coincident with a line of the iron spectrum which is now known to be 14 A distant. But measurements on photographs are now more precise, and it can be said that the wave-lengths of most of the unknown lines are reliable to within 1 A, and perhaps a dozen of the brighter lines are known to the nearest fifth of that unit. The wave-length of the principal coronal line can be guaranteed to perhaps 0.1 A. This inaccuracy is not to be considered as excessive, when it is remembered that eclipse spectrograms are of necessity hastily taken. In the half-century that coronal lines have been photographed and studied, the total time available for making these records has amounted to scarcely one hour.

The present investigation employs as a source of data the table of coronal lines prepared by Campbell and Moore.[2] After conclud-

[1] For an excellent account of our present knowledge of the corona consult S. A. Mitchell, *Eclipses of the Sun*, chaps. xviii, xix, 1923.

[2] *Lick Observatory Bulletin*, **10**, 10, 21, 1918.

ing their own important work at the eclipse of June 1918, these observers collected all the significant previous measurements made

TABLE I

THE CORONAL LINES

Line	λ, A.U., Air	ν, cm^{-1}	Intensity, etc.
c	3164	31 596	.....
d	3170	31 537	.....
e	3237	30 884	.....
f	3288	30 405	faint
A	3328.1	30 039	fairly strong°
a	3359	29 762	faint
B	3388	29 507	very strong*°
C	3455	28 935	strong°
g	3461	28 885	faint
h	3505	28 523	faint
b	3534	28 288	faint
D	3601.2	27 761	pretty strong*°
E	3626	27 571	faint
F	3641.3	27 455	rather faint
G	3642.9	27 443	rather faint*
H	3648	27 405	rather faint
i	3651	27 382	faint
I	3800.9	26 302	rather faint*°
j	3865	25 866	faint
k	3891	25 693	faint
J	3986.8	25 076	fairly strong*°
K	4085.9	24 468	fairly strong*°
l	4130	24 206	faint
L	4231.2	23 628	fairly strong*°
M	4241	23 573	faint
N	4244.6	23 553	faint
O	4311	23 190	faint
P	4359	22 935	rather faint*
m	4398	22 731	very faint
Q	4533.2	22 053	faint
R	4567	21 890	rather faint*
S	4586	21 799	rather faint
n	4722	21 172	faint
o	4725	21 158	faint
T	4779	20 919	faint
U	5073	19 707	faint
V	5118	19 533	faint
W	5302.9	18 852.4	very strong*°
p	5380.9	18 579	very faint
q	5393.3	18 536	faint
r	5433.4	18 400	rather faint
Y	5536	18 059	faint
s	5597.5	17 860	faint
t	5657.5	17 671	rather faint
Z	6374.0	15 684	strong*

by other astronomers; and their table gives what they consider to be the most probable values of the wave-lengths, and also qualitative estimates of intensity. Table I was prepared from this list by

converting the original Rowland wave-lengths to international angstroms in air, and then to vacuum wave-numbers. The designation of the lines by letters is for convenience, and in general, the better determined lines are given in capital letters. Lines having an asterisk opposite them in the intensity column are those observed consistently by a large number of workers, and lines marked with (°) are those which Stratton believes undoubtedly to belong to the corona.[1]

With these data available, it was natural to seek to identify the coronal lines with lines of elements found in the outer regions of the sun itself. Atoms of moderately heavy elements are known to be present at high chromospheric levels. The "H" and "K" lines of singly ionized calcium, for example, attain a height of 14,000 kilometers above the photosphere, or apparent solar surface, and ionized strontium, scandium, titanium, and iron are also found at great heights.

The theory of temperature ionization advanced by Saha, and amplified by Russell and by Fowler and Milne, offers a plausible explanation. By treating the process of ionization as a reversible chemical reaction, in which the neutral atoms are in equilibrium with the ionized atoms and the removed electrons, it is shown[2] that the presence of the ions at high levels is a result of the low pressures existing there. As a consequence, the presence and relative abundance of the elements in the solar spectrum receives an interpretation.

Pannekoek[3] has suggested that because of the presence of Ca^{+} far out in the solar atmosphere, Ca^{++} might be expected in the corona, and might be the source of the unknown lines. J. A. Anderson[4] has obtained accurate measurements of the vacuum spark spectra of calcium, including lines of the neutral, singly ionized and doubly ionized atoms. Comparison of the coronal wave-lengths with his tables showed that it was possible to associate twelve lines, but none are strong coronal lines, and the principal ray, W, of the corona has no match in the calcium list.

Now when the two valence electrons of the normal calcium atom

[1] *Memoirs of the Royal Astronomical Society*, **64**, 105, 1927.

[2] M. N. Saha, *Philosophical Magazine*, **40**, 472, 809, 1920.

[3] *Bulletin Astronomical Institute Netherlands*, Nos. 19, 21, 1922.

[4] *Astrophysical Journal*, **59**, 76, 1924.

are removed, the resulting structure is very much like the atom of argon, and the Displacement Law suggests a similarity in the spectra. In fact, the two atoms are so much alike that their most abundant isotopes have the same atomic weight—the only instance where this is known.

Perhaps the first step in the analysis of any line spectrum is the recognition of recurring differences of wave-number between pairs of lines. Accordingly, a systematic examination of the coronal numbers was made for the purpose of listing all such differences which could be significant. A map of the lines on a scale of wave-numbers was drawn, and eighteen sets of constant differences were located by a purely mechanical method. These were of course verified by direct computation, once their existence was suggested by the rapid method. From the mean error of the various members of a given set, the probability of the accidental occurrence of that group can be calculated.[1] For example, in the case of one interval, calculation gave, for the pure chance expectation of finding this, 0.521, while the number of pairs actually found in this set was 4; in another instance the chance expectation was 0.843, and 7 pairs were found, etc. In every case, the number to be expected on pure chance was small compared with the number actually found.

Meissner[2] has given, recently, a thorough analysis of the spectrum of argon, following closely the plan of Paschen's analysis for neon. The argon spectrum he showed to be built of ten p-, four s-, and twelve d-sequences; and a moderate array of terms account for several hundred lines of the spectrum. The constant differences originally found by Rydberg are embodied in the structure.

It was noticed that three of the coronal line-separations agreed with three of the chief term-differences in argon, viz.,

$$1s_5 - 1s_4 = 606.8 \text{ wave-numbers},$$
$$1s_3 - 1s_2 = 846.2$$
$$2p_2 - 2p_1 = 1226.2$$

The agreements are in each case within the accuracy to which the coronal wave-lengths are known.

Having at hand the suggestion offered by these relationships,

[1] W. M. Hicks, *The Analysis of Spectra*, p. 150.

[2] *Zeitschrift für Physik*, **39**, 172, 1926; **40**, 839, 1927.

it was natural to attempt, next, to identify coronal lines directly with argon lines. On comparing the coronal table with the argon lists,[1] twenty-two coronal lines, among them most of the prominent ones, were found to correspond to argon lines, within the accuracy to which the coronal lines are given. The directly identified lines, with the term designations (Meissner's notation, after Paschen), and the calculated wave-numbers, are shown in Table II.

The possibility of accidental coincidence in these identifications requires comment: The fourth column of the table gives the wave-numbers of the argon lines immediately before and after the one in question. These are in general far removed, compared with the differences between the coronal and argon wave-numbers. The average distance to the nearest line in the argon spectrum is thirty wave-numbers, while the largest departure of a coronal line from the argon line with which it is associated is five units, and the average departure is two. Further, the algebraic sum of these errors is negligible, supporting the idea that their existence is due merely to the inaccuracy inevitable in the coronal spectrograms.

Several other prominent lines, among them the chief coronal line, W, remain to be accounted for, at this stage. It was found that ten lines not appearing in the argon lists are expressible as intercombinations of Meissner's term values. Here again the disparities are tolerated only when within the uncertainty of the corresponding coronal data, and there are about equal positive and negative errors.

The first differences investigated above (p. 182) aided in the assignment of combinations. For example, the separation $K-L=\Delta_4=1s_3-1s_2$. Hence we should expect that the combinations giving these two lines should be of the form $K: 1s_3-t$ and $L: 1s_2-t$. It was found by systematic trial that the line K is given by $1s_3-4d'_4$. Hence the designation for L is $1s_2-4d'_4$. In this way, several of the combinations were revealed.

The bright green line, W, is given within half a unit of wave-number by two different combinations. The suggestion is that this line can be produced by two different changes in the configuration

[1] Meissner's papers referred to above; also H. Kayser's *Handbuch*, Band VI, and his *Hauptlinien*.

TABLE II

Directly Identified Lines

Line	ν, Corona	ν, Argon	Adjacent Lines in Argon	Combination
e	30 884	30 886	30 875 948	
A	30 039	30 038	29 987 30 058	
a	29 762	29 758	29 723 823	$1s_3-6p_{10}$
B	29 507	29 504	29 491 511	$1s_4-5p_7$
C	28 935	28 936	28 912 958	$1s_4-5X$
g	28 885	28 885	28 859 912	$1s_4-4p_3$
h	28 523	28 522	28 511 532	
D	27 761	27 761	27 757 768	
G	27 443	27 441	27 391 507	$1s_4-4p_8$
j	25 886	25 871	25 857 26 070	$1s_2-4p_6$
l	24 206	24 207	24 195 213	
M	23 573	23 572	23 558 597	
N	23 553	23 558	23 526 572	
O	23 190	23 193	22 888 23 253	
S	21 799	21 797	21 794 804	$2p_{10}-10d_5$
o	21 158	21 162	21 147 181	
T	20 919	20 923	20 904 957	
U	19 707	19 707	19 695 713	$2p_{10}-5s'_4$
V	19 533	19 533	19 526 551	$2p_8-6s'''_4$
q	18 536	18 534	18 524 545	$2p_6-6s_5$
r	18 400	18 399	18 391 402	$2p_2-10d_6$
s	17 860	17 860	17 857 879	$2p_3-6s'''_4$

of the radiating center, and the great intensity of the ray may be connected with this possibility. Now the possible error in the determination of the argon terms probably is not large enough to account for the difference in the two combinations, so that if both combinations are productive of radiation in the corona, it should be possible to detect, at future eclipses, doublet structure in this brightest coronal line. This would necessitate resolving two lines separated by about 0.1 A, a quite possible undertaking.[1]

TABLE III

COMBINATION LINES

Line	ν, Corona	ν, Calculated	Designation
d*	31 537	31 541	$1s_4-8d_1''$
b	28 288	28 288	$1s_4-5d_4'$
F	27 455	27 457	$1s_5-4s_1''$
i†	27 382	27 379	$1s_3-5d_5$
I	26 302	26 301	$1s_5-4d_1''$
k‡	25 693	25 694	$1s_4-4d_1''$
K	24 468	24 470	$1s_3-4d_4'$
L	23 628	23 624	$1s_2-4d_4'$
W	18 852.4	18 852.58	$2p_4-9s_4$
		18 852.17	$2p_3-7s_1''$
p	18 579	18 577	$2p_3-9d_4'$

* Kayser gives a line 31 540 { 31 519, 560

† Kayser gives a line 27 383 { 27 348, 387

‡ Kayser gives a line 25 690 { 25 685, 763

In locating combinations of terms to give coronal wave-numbers, there is, of course, chance for accidental agreement, especially when the number of terms is rather large, or where the sequential terms are close together. This possibility was investigated[2] and the probability of the accidental matching of the wave-numbers by term differences is, in every case, of the order of 10^{-3}.

The combination lines are displayed in Table III. The transition diagram on the following page shows the transitions corresponding to the combination lines, and also those corresponding to the

[1] It is interesting to note, in this connection, that J. C. McLennan (*Nature*, **115**, 46, 1925) found a broad line near λ 5300 when he excited solid argon to luminescence with cathode rays. In a private communication to the author, he pointed out that the instrument used was one of low dispersion; and the line in question may well be λ 5302.9.

[2] The reasoning followed in the case of the constant intervals (p. 182 and footnote 1), applies exactly here.

directly identified lines in the cases where the designations are known.

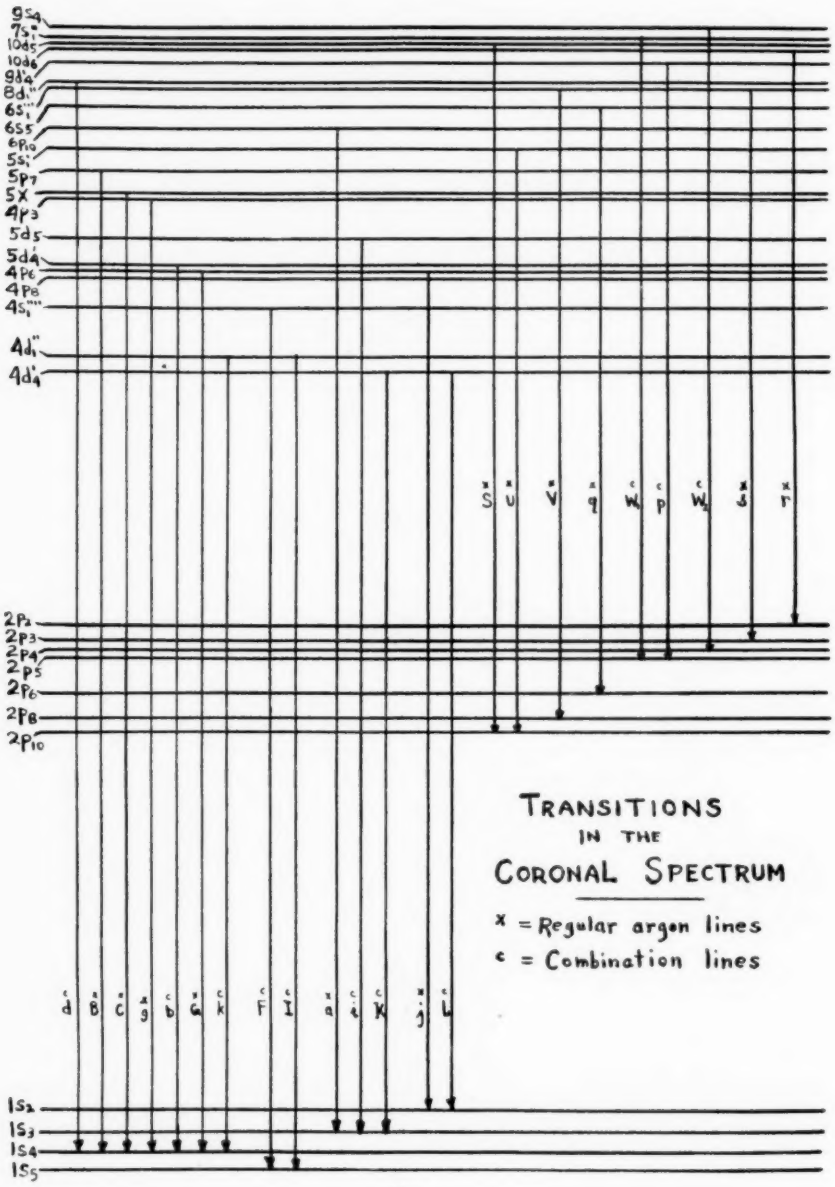

FIG. 1

In all, over two-thirds of the complete set of recorded lines of the corona are thus given an interpretation.

In order to see if it is possible to correlate the lines of the corona with the spectrum of some other substances, comparison was made

TABLE IV

COMPARISON WITH OTHER SPECTRA

Line	λ, Corona	λ, H Secondary	Adjacent H Lines	Intensity H Lines
j	3865	3865.477	3864.272 65.990	2
k	3891	3890.700	89.299 97.517	1
l	4130	4130.025	29.535 31.453	2
O	4311	4311.017	08.635 11.701	oo
P	4359	4358.537	57.045 61.915	oo
m	4398	4398.081	96.893 98.239	1
R	4567	4567.753	65.544 68.130	o
S	4586	4586.120	85.116 86.591	od
n	4722	4721.542	21.000 23.032	3
o	4725	4724.820	23.838 26.144	4
U	5073	5072.621	72.307 75.442	1
V	5118	5118.961	17.390 20.131	o
p	5380.9	5380.973	79.975 81.709	o
Y	5536	5535.980	34.475 36.353	5

with a number of spectra, including those of prominent solar elements. The secondary spectrum of hydrogen is exceedingly rich in lines, and the coronal lines were compared with it[1] for the purpose of seeing how many coincidences would result. It was possible to associate fourteen lines (Table IV); but the adjacent lines are so close that the identification is by no means unique, and further-

[1] Gale, Monk, and Lee, *Astrophysical Journal*, **67**, 89, 1928.

more, the most important lines of the corona remain without mates in the hydrogen list. The quotient of the average distance to adjacent lines by the average error in identification is 4.5 here, whereas it was (cf. p. 183) $\frac{30}{2}=15$ in the argon comparison.

The other spectra examined, together with the number of possible identifications, are shown in Table V. In no spectrum examined does the green ray, or more than one or two of the other brighter lines, appear.

The following eleven lines which appear in the complete data of Campbell and Moore (Table I), have not been accounted for in the present work: c, f, E, H, J, m, n, t, Q, Y, Z. All of these, with

TABLE V

Element	Possible Agreements	Element	Possible Agreements
Ca I, II, III	12	*Co*+	2
Mg+	2	*Va*+	2
Sr+	0	*Ti*+	3
Ba+	3	*Ne*	6
Tl+	1	*Xe*	7
Li	0	*He*	2
K+	1	*O, N*, ionized	5
Cr+	1		

the exception of J, t, Q, Y, and Z are lines which Davidson and Stratton[1] believe should be removed from the coronal list. Of these, f, E, and H fall close to the positions of chromospheric Ti^+ and *Fe* lines, with which they might be confused, while the rest, with the exceptions mentioned, are, according to these investigators, lines whose existence is regarded as very doubtful.

Using the argon tables, the pairs of lines which encompass the foregoing eleven were picked out, and the separation of the coronal line from each of the adjacent argon lines was calculated. The average was fifty-seven wave-numbers. As stated on a previous page, the average disparity between the coronal wave-numbers and those of argon with which they were associated was found to be two, with a maximum of five. Also the average distance to the adjacent lines in argon was in this case thirty wave-numbers.

[1] *Memoirs Royal Astronomical Society*, **64**, 105, 1927.

Taking, therefore, the entire list of lines of undoubted coronal origin, according to the latest work, this totals thirty-eight lines. Of these, the present investigation accounts for thirty-three.

Hypotheses as to the means by which various celestial spectra are stimulated are especially interesting. The recognition of the importance of thermal ionization has not only clarified certain problems in solar and stellar spectroscopy, but has drawn attention to pertinent laboratory problems in connection with electric furnace spectra. In cosmic bodies other than stars, temperature cannot be directly the main factor, and other sources must be considered. Thus in order:

> to account for the nebular spectrum we must find some process which is capable of feeding large amounts of energy into individual atoms, here and there, in a cold and exceedingly rarefied gas. The only known ways in which this happens are by collisions with electrons of high speed, and by the absorption of radiation of very short wave-length. The only source of either of these which comes at all into consideration from the astrophysical standpoint is a very hot body.[1]

The excitation by light-quanta has been utilized by Bowen[2] in developing a physical theory of the structure of the planetary nebulae. In connection with Bowen's work, Woltjer has asked[3] why the metastable transitions are so strong compared with regular transitions; and to answer this, Eddington[4] proposes to add to Bowen's original stipulation of low pressure the condition that "the stimulating radiation be so weak that the atom is unlikely to absorb a quantum during the full duration of the metastable state." Discussing the emission of the coronal lines from the same point of view, Eddington concludes that metastable transitions are not involved here. The density, he points out, may be low enough, but the incident radiation is too intense, so that if metastable states are concerned at all, they must be of short life.

Meissner interprets some of his recent experiments[5] as indicating that the $1s_3$ and $1s_5$ states in argon are metastable. The transi-

[1] Russel, Dugan, and Stewart, *Astronomy*, p. 838.

[2] *Astrophysical Journal*, **67**, 10, 1928.

[3] *Bulletin Astronomical Institute Netherlands*, No. 138, 1927.

[4] *Monthly Notices*, **88**, 134, 1927.

[5] *Annalen der Physik*, **84**, 1009, 1927.

tions involved in the correlation of the coronal and argon spectra have no jumps from these states among them, but several transitions terminate at these states, as is true of a great many other lines of the red spectrum.

S. J. Brown[1] found that the lines C, G, I, and J have a similar distribution in the corona, and with this group, Pannekoek has also associated K and L. Also B has a distribution similar to that of W, and Pannekoek indicates that D is also related to these two lines. Stratton, more recently, groups C with G, and D and K with W, as well as B and J with Z. All the observations cited have in common the linking of C with G, and the linking of W with D. In the latter pair, the term designation for D is not known. In the former pair, both the lines have the same final state, $1s_4$. Further observational work, of a quantitative nature, on the spatial distribution of the bright lines may reveal important connections.

S. A. Mitchell has proposed a "Photo-Electric Theory of the Corona" in which he assumes that the solar radiations of short wave-length set free electrons from the atoms in the chromosphere, and these electrons, driven outward into the corona by the magnetic field and other influences, excite radiation in the coronal materials.[2] The variations in form of the corona with the sun-spot cycle thus receive an interpretation; for the spots are undoubtedly roots of intense local magnetic forces, and probably also sources of electrons. Sir Norman Lockyer noticed that marked filamented structures in the corona were associated in position with prominences; and we now know that prominences, in turn, often arise in the immediate vicinity of sun-spots, so that a connection between coronal structure and the distribution of spots is certain. Further, it is known that the bright lines of the corona are more intense at time of greatest sun-spot activity. To explain these phenomena by appealing to excitation by radiation alone is difficult; for the region above a spot is relatively *deficient* in radiation, and the spots look black against the rest of the solar surface.

[1] *Astrophysical Journal*, **12**, 63, 1900.

[2] *Eclipses of the Sun*, chap. xix. See there also a review of other theories of the physical nature of the corona.

The ionization potentials of neutral and of singly ionized argon are given by Bloch and Dejardin[1] as 15.2 volts and 19 volts respectively. It is then possible to make rough calculations on the degree of ionization of this element in the photosphere and in the corona. The percentage ionization according to the theory of thermal ionization was calculated[2] for several temperatures and pressures, and

TABLE VI

PERCENTAGE IONIZATION OF ARGON IN THE CHROMOSPHERE AND IN THE CORONA

(*a*) CHROMOSPHERE

p	10^{-8} A.
T 5000.....	AI: < 2% AII: < 0.5
6000.....	AI: 13% AII: < 0.5

(*b*) CORONA

p	10^{-16} A.	10^{-14}	10^{-10}
T 3000.....	AI: 50% AII: 1	5.5%	
4000.....	AI: AII:	80% < 0.5	< 2 → 0
5000.....	AI: AII:	→complete 14	16 < 0.1
6000..... .	AI: AII:		80 2.5

the results appear in Table VI. In the chromosphere the degree of ionization for the atom and for the ion is small. But at the higher temperature of 6000°C., there might be considerable dissociation of the neutral atoms. In the corona, the much reduced pressures allow a higher degree of ionization for both types of atom. The conditions $p = 10^{-14}$ Atm., T = 5000°C. is probably a good estimate for the inner corona, while for regions farther out, the circumstances $p = 10^{-16}$ Atm., T = 3000°C. are reasonable. Coronal observations

[1] *Annales de physique*, **2**, 241, 461, 1924.

[2] A convenient set of curves is given in Andrade, *Structure of the Atom* (3d ed.).

show that the bright lines originate mainly in the inner and intermediate regions. This is probably because the decrease in pressure with distance outward is less abrupt than the decrease in temperature, since radiation pressure and the impact of projected electrons both tend to lessen the rate at which the pressure falls off.

According to Bloch and Dejardin, the "red" spectrum of a rare gas is that of the arc, while the "blue" spectrum probably corresponds, in the main, to the first, second, and even higher spark spectra.

There are several lines in the group identified with the corona, which are observed in argon spectra, but which Meissner was unable to fit into series. It may be that these correspond to higher spark lines, especially those ascribed to the blue spectrum. In particular, the wave-number difference of the coronal lines O and N is close to a term-difference in AII recently found by DeBruin.[1] These are two lines observed by Meissner in the blue spectrum, with equal intensity.

W. Anderson has proposed an electron-gas theory of the structure of the corona, which has several remarkable features.[2] It is assumed that the corona consists of a cloud of electrons set free from atoms in the sun. But if the sun were to retain the high positive charge of the residue, it would not be possible for electrons to escape to great distances, and the wide extent of the corona would be without explanation. He finds it necessary to draw an analogy between the apparent indifference of the projected electrons to the retarding positive charge, and the corresponding effect in laboratory experiments on the passage of slow electrons through atoms, the Ramsauer effect.[3] This effect is more pronounced in argon than in other gases,[4] and the view is here offered that the projection of argon into the corona is aided by an *actual* Ramsauer effect with electrons. These atoms would, of course, come originally from the chromosphere; and their high degree of peripheral symmetry

[1] *Nature*, **121**, 576, 1928.

[2] *Zeitschrift für Physik*, **41**, 51, 1927. See there references to five previous papers on the same problem by the same author.

[3] *Annalen der Physik*, **64**, 540, 1921.

[4] *Handbuch der Physik*, **23**, 650, 1926.

would make it more likely that they, rather than atoms of other kinds, would be driven outward by radiation pressure and electronic impact. In the inner corona, where the outward-moving electrons have the greatest energy, these collisions would excite the greatest number of atoms, and the coronal lines would be brightest in this region, as observed.

The relatively few electrons arrested by coronal atoms would emit a continuous spectrum ("Bremsspektrum") on being retarded, thus accounting for that small part of the continuous radiation which is believed to originate in the corona itself.

It is a pleasure to express sincere gratitude to Dr. H. B. Lemon for suggesting the problem, and for aid and encouragement during its development; and acknowledgment is due to Dean H. G. Gale for suggestions and criticism.

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TEMPERATURE CLASSIFICATION OF THE STRONGER LINES OF CERIUM AND PRASEODYMIUM[1]

By ARTHUR S. KING

ABSTRACT

Previous results for cerium and praseodymium, confined largely to measurements of wave-length, have been extended by studying the dependence of line-intensity upon the conditions of the source, with special attention to the distinction between lines of the neutral and ionized spectra. Lines arising from the two states were segregated by a comparison of furnace, arc, and spark spectra. This was facilitated by mixing caesium with the elements studied, which suppresses the ionized lines appearing normally in the furnace. The resemblance between the arc and spark spectra of rare-earth elements in the blue and violet has frequently been noted. The furnace is especially effective in this region for the lines of the neutral atom, which in these spectra are faint in the arc at shorter wave-lengths and have been to a large extent unrecognized. In agreement with astrophysical evidence, it indicates that the prominent lines of cerium and praseodymium here belong to the ionized atom. At greater wave-lengths, the neutral lines are stronger and form a large part of the arc spectrum.

The relative energy-levels at which the more sensitive lines originate are indicated as usual, for the neutral lines, by their behavior at different temperatures, and, for ionized lines, by the degree to which they persist in the furnace spectrum.

The lines classified number 1362 for cerium and 1018 for praseodymium. These were selected from the very rich spectra on the basis of usefulness for identification of the elements in either the neutral or ionized states, and as probably the lines of lower energy-levels in each condition of the atom. A distinct variation in general intensity with wave-length is noted for both the neutral and singly ionized spectra, and, further, that certain lines of each element appearing in the near ultra-violet probably arise from the doubly ionized state.

The lines listed were selected not only from the available tables, but also from the large number of neutral lines measured in the furnace spectrum by the writer, which number about 1700 for cerium. Most of these had not been measured previously, since in the arc they are relatively weak or obscured by blends. Of the ionized lines selected, many appear in the furnace spectrum, and in the case of praseodymium, even at moderate temperatures.

A notable feature of the praseodymium spectrum is the large proportion of highly complex lines, nearly 40 per cent of those included in Table II being of this class. The number and arrangement of their components are given as an aid to the series grouping of lines of similar type. Preliminary spectrograms made with high dispersion give improved resolution of the fine-structure patterns.

The spectra of the rare earths may be said to stand at present on the frontier of spectroscopic investigation, the available data consisting chiefly of measurements of wave-length which are themselves in a preliminary stage, lacking completeness and often accuracy. An explanation of this condition is found in the extreme richness of the spectra of the rare earths and in the difficulty, owing

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 368.

to the extraordinary chemical affinity of these elements for one another, of isolating a spectrum for intensive study. Among the rare-earth elements of atomic numbers 57 to 71 inclusive, so fundamental a distinction as that between lines of the ionized and neutral atoms has been made only for lanthanum.[1]

The writer has been engaged for some time on an investigation of the spectra of cerium, praseodymium, neodymium, and samarium as produced in the furnace at various temperatures, as well as in the arc and the spark. The present paper gives the data for the first two of these elements. The distinction between neutral and ionized lines was first established. Next the stronger lines of each type were assembled and classified according to their response to the various excitations, which should indicate approximately the levels from which the lines arise in both the neutral and ionized states.

A peculiar situation exists in regard to the arc and spark lines of these rare earths, of which cerium, the most frequently studied, may be taken as typical. Various observers have noted that the arc and spark spectra are much alike. This, as will be shown, is not true in the region of greater wave-lengths, but is so conspicuous in the violet and blue as to have been noted repeatedly by Kayser in his summaries. A comparison of the arc and spark tables of Exner and Haschek shows scarcely any lines stronger in the spark than in the arc, so that the term "enhanced lines" ceases to apply. Astronomical evidence, especially that from chromospheric spectra, in which many of the stronger lines of the rare earths have been identified, indicates that these belong to the ionized atom. If this is the case, the question arises as to what lines make up the spectrum of the neutral atom. Such lines presumably would be the chief lines of the spectrum from the electric furnace, while the ionized lines would be relatively weak. Experiments gave a furnace spectrum which on first examination had little resemblance to the arc spectrum. It was found, however, that all the lines of the rich furnace spectrum could be detected as faint lines on arc spectrograms, unless, as very frequently happened, they were masked by strong lines of the arc. The spark spectrum, on the other hand, failed to show

[1] *Mt. Wilson Contr.*, No. 326; *Astrophysical Journal*, **65**, 86, 1927.

these furnace lines. The obvious conclusion is that the dominant lines of the arc, as well as of the spark, are those of the ionized atom, while the neutral lines make up the furnace spectrum and are present, though inconspicuous, in the arc spectrum. Examination of the tables of wave-length showed that the stronger lines of this kind, unless concealed by blends, had usually been measured in the arc spectrum. These blends are so disturbing in the arc that comparatively few neutral lines have been measured in the violet and blue. More of this type have been measured in the green, while in the yellow and red the ionized lines are of lower intensity and a large proportion of the lines previously identified are those of the neutral atom.

The distinction thus made between the neutral and ionized spectra was confirmed by the method, developed in previous work,[1] of using in the furnace a mixture of the element studied with caesium. Caesium, having a low ionization potential, furnishes a large supply of free electrons; recombination is thus increased, with the result that atoms in the ionized state are relatively few. In the case of both cerium and praseodymium, many of the lines, considered on other evidence as belonging to the ionized atom, appear in the furnace spectrum. A mixture with caesium, vaporized at the same temperature as when cerium or praseodymium was used alone, results in a general quenching of these lines, while the lines regarded as belonging to the neutral atom are unaffected. The method was of special service in the case of lines whose arc behavior would class them as ionized, but which are of considerable strength in the furnace. These might be neutral lines of high-temperature class, but when they were suppressed by the caesium mixture, it was clear that they were low-level lines of the ionized atom.

The question arose, as it has with everyone working with rare-earth spectra, as to how far completeness should be aimed at by the inclusion of the fainter lines. The purpose of the present paper is twofold: first, to supply a list of both neutral and ionized lines sufficiently large and well-distributed to give easy identification of either type in astronomical or other spectra in which these elements may be suspected; and secondly, to provide a beginning for the analysis of the spectra by listing those lines whose strength in the fur-

[1] *Mt. Wilson Contr.*, No. 233; *Astrophysical Journal*, **55**, 380, 1922.

nace, or decided prominence in the arc, classes them as lines of low atomic level for either the neutral or the ionized states. It thus seemed advisable to omit for the present a very large number of lines which are not needed either for purposes of identification or for preliminary analysis.

Instrumental equipment.—All of the spectrograms, except those taken to show the fine structure of praseodymium lines, were made with the 15-foot concave-grating spectrograph, the second order, with a dispersion of 1.86 A per mm, being used for wave-lengths shorter than λ 5400, while the first order was used for the yellow and red regions and for some low-temperature exposures where maximum brightness was needed.

The operation of the vacuum furnace involved no unusual features. The regular tubes were used, of highly purified graphite, 12.5 mm internal diameter, with a length of 20 cm heated. The rare-earth compound was introduced in powdered or fused form, and as apparently no compound was formed with the carbon, the vapor diffused out of the tube in a short time, thus requiring several renewals in the case of long runs at low temperature. The use of a shallow graphite combustion boat helped somewhat to retain the material in the tube and to avoid an explosive scattering at the start of the heating. The interval during which a good supply of the rare-earth vapor remained in the tube could be gauged by the characteristic color of the image on the spectrograph slit.

Measurements of wave-length were provided for by spectrograms taken especially for this purpose. Iron, mixed with the rare-earth compound in the furnace tube, provided good standards, well distributed, for use in making the desired measurements.

The usual procedure for a given region was to make furnace spectrograms at three temperature stages, one at 2600°–2700° C, another near 2400° C, and a third at 2000°–2100° C, although a somewhat lower limit was used in the case of praseodymium. Additional spectrograms made with a mixture of rare earth and iron, and frequently on emulsions of high contrast, were often included in a set. For the comparison arc spectra, the rare-earth compound was placed on the positive terminal of a carbon arc. The selection of ionized lines required a spark spectrum for each region. For this, a spark

of considerable power was drawn from a 10-kw transformer, giving 40,000 volts, with condenser and spark-gap. The lower electrode was formed by boring out a 6-mm graphite rod, leaving a very thin wall. This tube was filled with a thick solution or paste of the material to be examined, the supply being renewed from time to time. The upper terminal was a pointed graphite rod. Each electrode was held in a massive brass clamp for cooling.

CERIUM

It was soon clear that the first task was the segregation of the ionized and neutral cerium lines, and further that the measurement of a large proportion of the neutral lines would be necessary. The stronger neutral lines, when not concealed (as very often happens) by blends in the arc with lines ascribed to ionized cerium, have been measured by other observers. Those which they did not measure are clearly of the same type, but are either masked in the arc by other lines or are below the limit which measurers of the arc spectrum set for themselves, since a complete listing of all lines appearing in the cerium arc has never been attempted.

As a further check on the correctness of identifying these lines with cerium, a set of furnace spectrograms was made with highly purified cerium nitrate, prepared in the chemical laboratory of the University of Illinois and supplied through the kindness of Professor B. S. Hopkins. Lines which I have listed as *Ce* I appeared on these plates, as well as on those taken with a preparation of cerium chloride which gave no evidence of troublesome impurities.

The region in which the previous measurements have failed, through neglecting the fainter lines in the arc spectrum, to give an adequate list of the neutral lines, is from λ 3000 to λ 4700. Absorption spectra may show *Ce* I lines below λ 3000, but the emission spectrum, with the tube at about 2700° C, ends near this limit. As the blue region is approached, an increasing proportion of fairly strong lines appears, and in the green, some lines compare in strength with neighboring *Ce* II lines. To the violet of λ 4700, about 1600 *Ce* I lines were measured by the writer, the few neutral lines already listed in the tables being included in this number. At wave-lengths greater than λ 4700, the prominence of the neutral spectrum is

shown by the fact that it was necessary to measure only about 100 of the stronger lines as far as λ 7000, the existing tables in the main being adequate.

Table I includes 1362 lines, selected in accordance with the purpose of this paper. A large proportion of the neutral lines of shorter wave-length, being of low intensity, have not been listed, and the number of ionized lines included is but a small part of the stronger lines of ionized cerium. An effort has been made, however, to include ionized lines of such strength and isolated position as to be useful in identifying the spectrum, and especially those whose appearance in the furnace marks them as arising from the lower levels of the ionized atom. Users of the table who wish more complete lists of ionized lines may take the stronger lines from the arc lists of Klein,[1] Bakowski,[2] Kiess,[3] or Exner and Haschek.[4] If they are true cerium lines and are not given as neutral in Table I, they may safely be taken as belonging to the ionized spectrum.

The first column of Table I gives wave-lengths on the international system, each value having a small number after it, denoting the source of the wave-length. These sources are as follows:

1. King, furnace
2. Klein, arc
3. Exner and Haschek, arc (converted to I.A.)
4. Kiess, arc

Unresolved doublets are indicated by "d"; an asterisk following the wave-length refers to a note at the end of the table. The wave-lengths of ionized lines to the violet of λ 4550 were taken in nearly all cases from the table of Klein, who also measured some of the neutral lines here credited to the writer. From λ 4550 to λ 5500, all ionized and many neutral lines have Exner and Haschek wave-lengths (converted), while from λ 5500 on the values are those of Kiess supplemented by measurements of the writer.

The estimates of arc intensities in the second column show the large difference, especially at shorter wave-lengths, between the gen-

[1] *Zeitschrift für wissenschaftliche Photographie*, **18**, 45, 1919.

[2] *Ibid.*, **4**, 74, 1906.

[3] *Scientific Papers of the Bureau of Standards*, **17**, 317 (No. 421), 1921.

[4] *Spektren der Elemente bei normalem Druck* (Leipzig, 1911).

eral intensities of neutral and ionized lines. This difference varies with fluctuations in the arc, but is always large and, since a majority of the lines are weaker than those entered here, this explains why the neutral spectrum has to a large extent been unobserved.

The furnace intensities in the third column are for the medium temperature stage of about 2400° C, except for the difficult region below λ 3400, where a temperature of 2700° was required to bring out a fair number of neutral lines. While not entered in the table, the intensities of lines at higher and lower temperatures were taken into account in assigning the classes.

The usual scale of temperature classes is employed, the more decided low-temperature lines being placed in class I, those strengthening rapidly at medium temperature in class II, while lines requiring successively higher temperatures belong in classes III, IV, and V. Lines of the ionized atoms are distinguished by "E" after the class number, while the addition of "A" to the class of a neutral line denotes that it is relatively much stronger in the furnace than in the arc.

The method of selection results in placing the neutral cerium lines largely in classes I and II, most of the lines which would fall into higher temperature classes being omitted from the present list. In the yellow and red, however, a larger proportion of lines came out easily at low temperature. These were grouped in classes I and II, while many lines strong at medium temperature go into class III. As regards ease of production in the furnace, violet and blue lines of classes I and II are comparable with yellow and red lines of classes II and III, respectively. No attempt is made here to list the very large number of fainter furnace lines which would go in classes IV and V.

The lines of ionized cerium are usually very faint in the furnace, but in the short-wave region a large number appear distinctly and are placed in class IVE. Some of these, while very strong in the arc, have as high intensities in the furnace as the average neutral lines, and the test with a mixture of caesium was required to decide that the effect was not due to a coincidence of neutral and ionized lines. Such lines may be expected to be among the lines of lowest energy-level in the ionized spectrum.

TABLE I

TEMPERATURE CLASSIFICATION OF CERIUM LINES

λ (I.A.)	INTENSITIES		CLASS	λ (I.A.)	INTENSITIES		CLASS
	Arc	Furnace			Arc	Furnace	
2976.904[2]	100	.....	VE	3159.317[1]	2	5	IIA
2990.872[2]	80	.....	VE	3159.730[1]	6	8	II
2995.644[2]	80	.....	VE	3164.157[2]	200	2	VE
3006.620[1]	3	3	II	3169.150*[1]	?	6	II
3008.788[2]	125	.....	VE	3169.181*[2]	150	?	VE
3011.034[1]	2	2	II	3169.395[1]	8	8	II
3014.563[1]	4	4	II	3171.618[2]	200	2	VE
3017.196[2]	80	.....	VE	3181.640*[1]	5	5	II
3017.769[1]	5	3	II	3183.524[2]	250	2	VE
3024.592[1]	5	4	II	3185.416*[1]	6	10?	I?
3029.870[1]	3	3	II	3186.124[2]	125	1	VE
3030.232*[1]	6	6	II	3191.093[1]	8	8	II
3037.728[1]	80	.....	VE	3193.975[1]	3	6	IIA
3051.977d[2]	60	.....	VE	3194.821[2]	200	2	VE
3053.297[1]	10	7	II	3201.712[2]	300	2	VE
3055.241[2]	150	.....	VE	3205.000[1]	4	6	II
3056.778[2]	200	1	VE	3207.172[1]	5	5	II
3061.236*[1]	6	5	II	3212.598[1]	20	15	I
3063.011[2]	400	2	VE	3216.690[1]	6	8	II
3063.109*[1]	4	5	II	3218.945[2]	200	1	VE
3083.670[2]	100	.....	VE	3221.172[2]	250	2	VE
3087.162[1]	10	8	II	3222.617[1]	10	10	I
3089.803[1]	5	5	II	3222.846[1]	3	4	II
3091.285*[1]	7	5	II	3225.634*[1]	?	8	II
3103.367[2]	125	1	VE	3227.116*[2]	300	4	VE
3105.875[1]	3	3	II	3227.136[1]	?	6	II
3110.279[2]	100	.....	VE	3231.240[2]	200	2	VE
3111.808[1]	3	6	IIA	3234.272[2]	300	3	VE
3112.974[1]	4	6	II	3235.022[1]	4	4	II
3116.280[1]	5	5	II	3236.738[2]	150	1	VE
3121.495[1]	4	5	II	3236.859[1]	10	10	I
3122.625[1]	10	8	I	3238.909[1]	3	3	II
3127.529[2]	80	.....	VE	3240.393[1]	3	4	II
3128.898[1]	4	6	II	3241.372[1]	2	4	IIA
3132.041[1]	5	6	II	3243.370[2]	200	2	VE
3134.602[1]	6	8	II	3246.672[2]	60	.....	VE
3137.393[1]	2	5	IIA	3248.552[1]	6	8	I
3139.000[1]	3	6	IIA	3251.393[1]	4	6	II
3139.188[1]	5	6	II	3252.482[2]	30	.....	VE
3144.375[1]	12	12	I	3254.691[1]	2	5	IIA
3145.283[2]	150	2	VE	3257.844[1]	3	5	II
3146.412[2]	200	2	VE	3259.571[1]	6	8	II
3153.346[1]	5	6	II	3260.974[2]	60	2	VE
3153.451[1]	3	5	II	3264.724[1]	3	5	II
3156.885[1]	3	6	IIA	3266.091[1]	4	4	II

TABLE I—*Continued*

λ (I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
3270.134*1..	8	6	II	3357.211²..	125	1	VE
3272.252²....	250	2	VE	3359.300¹..	12	10	I
3272.742¹....	10	12	I	3359.437d?1	10	15	II
3272.939¹....	6	8	I	3360.273¹..	6	6	II
3274.863²....	150	1	VE	3360.539²..	75	.....	VE
3277.134¹....	5	6	II	3361.238¹..	12	10	II
3279.841²....	125	1	VE	3362.921¹..	5	5	II
3282.327¹....	3	5	II	3364.006¹..	8	8	II
3283.909¹....	4	8	IIA	3365.842*1.	15	10	I
3285.227²....	125	1	VE	3366.552²..	150	?	VE
3286.039*1..	?	10	II	3366.564*1.	?	10	II
3286.549¹....	2	8	IIA	3369.098¹..	8	10	I
3288.579¹....	3	4	II	3370.407¹..	10	10	I
3289.800¹....	3	4	II	3370.863¹..	5	6	II
3289.950¹....	8	8	II	3371.061¹..	8	8	I
3295.281²....	80	1	VE	3372.538¹..	8	8	I
3296.879²....	40	.....	VE	3373.457²..	100	.....	VE
3298.195¹....	10	12	I	3373.731²..	125	1	VE
3300.151²....	60	1	VE	3377.125²..	300	3	VE
3304.837²....	60	.....	VE	3379.172²..	100	1	VE
3308.277¹....	5	8	II	3383.788¹..	5	5	II
3311.459*1..	?	12	I	3385.338¹..	15	10	I
3312.219²....	50	1	VE	3389.636¹..	15	10	I
3314.725²....	100	1	VE	3393.585d*1	12	12	I
3316.539*1..	6	8	II	3393.918²..	50	.....	VE
3317.795²....	30	1	VE	3395.415¹..	8	10	I
3322.167¹....	3	3	II	3398.965¹..	12	8	II
3323.093¹....	6	8	II	3399.081¹..	4	5	II
3324.588¹....	6	6	II	3405.980²..	100	1	VE
3325.331²....	50	1	VE	3408.382¹..	6	6	II
3328.002¹....	8	10	I	3416.701¹..	15	12	I
3330.636¹....	6	6	II	3417.451²..	125	1	VE
3331.421¹....	8	8	I	3420.958¹..	12	10	II
3332.206¹....	8	8	II	3421.070¹..	8	8	II
3334.449²....	60	.....	VE	3422.706²..	300	4	VE
3337.898¹....	5	6	II	3426.205²..	250	4	VE
3341.292¹....	12	10	I	3428.870¹..	8	8	II
3341.873*2..	100	?	VE	3433.078²..	50	.....	VE
3343.249¹....	5	5	II	3433.131*1.	?	6	II
3343.861²....	200	2	VE	3434.133¹..	8	8	II
3344.760²....	300	3	VE	3435.198*1.	30	20	I
3345.238¹....	4	4	II	3436.197¹..	8	8	II
3345.432¹....	9	6	II	3437.823*1.	35	20	I
3348.194¹....	10	8	II	3439.432¹..	4	6	II
3352.298*1..	?	6	II	3439.831²..	60	1	VE

TABLE I—*Continued*

λ (I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
3441.208²	150	2	VE	3534.043²	300	4	VE
3442.249¹	6	6	II	3537.432*¹	?	15	I
3442.383²	75	1	VE	3537.854¹	5	5	II
3443.553¹	20	8	II	3538.965¹	5	5	II
3446.207¹	15	8	II	3539.072²	300	4	VE
3452.218¹	5	5	II	3540.117¹	4	4	II
3452.806¹	5	5	II	3546.182*²	150	2?	VE
3454.803¹	30	15	I	3548.167¹	12	10	I
3459.147¹	8	10	II	3552.367¹	4	4	II
3460.992¹	5	8	II	3554.993*²	150	?	VE
3461.304¹	8	8	II	3560.795*²	500	?	VE
3461.423¹	4	6	II	3569.837¹	8	8	II
3462.437¹	12	12	I	3571.460¹	4	4	II
3468.068*¹	6	6	II	3577.446*²	500	?	VE
3468.986*¹	10	8	I	3583.586¹	6	6	II
3470.018¹	10	10	I	3590.595²	125	1	VE
3476.839²	150	.....	VE	3591.747¹	4	5	II
3484.054¹	5	8	II	3597.230¹	8	8	II
3484.552¹	6	8	II	3597.571¹	4	4	II
3485.060²	400	10	IVE	3598.190²	50	.....	VE
3486.864¹	12	10	I	3600.580²	60	.....	VE
3488.559²	75	1	VE	3603.725¹	8	8	II
3489.468¹	5	5	II	3606.129¹	12	12	I
3490.264¹	10	8	II	3607.627²	200	5	IVE
3491.700¹	15	12	I	3608.303¹	4	4	II
3492.488¹	6	6	II	3609.229¹	3	3	II
3494.870¹	4	8	IIA	3609.690²	250	2	VE
3496.443¹	5	6	II	3612.469¹	10	10	I
3501.343¹	8	10	I	3613.700²	150	3	VE
3501.458²	60	1	VE	3614.250¹	4	5	II
3501.597¹	15	12	I	3616.469¹	8	8	I
3504.145¹	6	8	II	3622.149²	100	1	VE
3507.348¹	10	10	I	3622.943¹	4	4	II
3507.944²	125	2	VE	3623.840²	60	1	VE
3509.536¹	4	5	II		200	2	VE
3510.222¹	12	12	I	3625.373¹	10	10	I
3512.268¹	8	10	I	3628.618¹	20	15	I
3517.382²	300	2	VE	3629.807¹	8	8	I
3517.499¹	4	4	II	3630.153¹	10	10	I
3518.497¹	8	8	II	3631.191²	125	2	VE
3519.012¹	8	10	I	3637.574¹	10	12	I
3520.522²	150	2	VE	3643.453¹	10	15	I
3521.533¹	3	3	II	3646.963²	200	4	VE
3521.878²	200	1	VE	3647.543¹	6	8	II
3531.620¹	12	12	I	3648.530¹	6	10	II

TABLE I—*Continued*

λ (I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
3651.534[1]	4	6	II	3746.401*[1]	?	10	II
3653.109[2]	125	4	VE	3746.573[1]	5	8	II
3653.669[2]	250	8	IVE	3747.549[1]	10	10	II
3654.977*[1]	?	8	II	3748.059[2]	150	4	IVE
3655.021[1]	6	8	II	3755.421[2]	75	3	IVE
3655.848[2]	500	12	IVE	3756.264[1]	12	12	I
3658.789[1]	8	12	I	3759.757[1]	20	15	I
3659.227[2]	125	5	IVE	3763.117[1]	2	4	IIA
3660.640[2]	250	8	IVE	3764.118*[2]	150	4?	IVE
3660.698[1]	6	6	II	3766.068[1]	15	15	I
3666.023[1]	30	25	I	3766.850[1]	4	6	II
3667.980[2]	400	8	IVE	3781.621*[2]	150	4?	IVE
3671.303[1]	4	6	II	3782.524*[2]	75	4?	IVE
3672.176*[1]	?	15	I	3785.016[1]	8	8	II
3672.790[2]	60	1	VE	3786.634[2]	150	5	IVE
3679.075[1]	5	10	IA	3788.754[a]	75	5	IVE
3679.425[2]	50	tr	VE	3789.469[1]	10	10	I
3686.050[1]	12	12	I	3791.961[1]	10	10	I
3687.800[2]	30	tr	VE	3792.325[2]	50	1	IVE
3689.677[1]	15	15	I	3799.098[1]	5	5	I
3690.121[1]	12	12	I	3801.526*[2]	500	10?	IVE
3694.910[2]	60	1	VE	3803.098*[2]	200	?	IVE
3699.917[2]	50	1	VE	3803.832[1]	8	5	II
3702.246[1]	4	5	I	3807.940[1]	3	10	IA
3706.863[1]	4	6	II	3808.118*[2]	300	?	IVE
3706.932*[1]	?	6	II	3815.832*[2]	250	?	IVE
3707.884[1]	4	8	IIA	3823.903[2]	50	.....	IVE
3709.287[2]	400	5	VE	3834.555*[2]	100	?	IVE
3709.932[2]	500	15	IVE	3838.543[2]	150	4	IVE
3711.650[1]	3	6	IIA	3848.600*[2]	150	?	IVE
3716.365[2]	600	15	IVE	3853.166*[2]	125	?	IVE
3717.767[1]	5	8	II	3854.194*[2]	100	?	IVE
3718.191[2]	150	10	IVE	3854.326*[2]	100	?	IVE
3718.377[2]	200	3	VE	3877.125[1]	5	5	II
3723.668[1]	15	15	I	3878.373*[2]	150	?	IVE
3724.232[1]	3	4	II	3882.453*[2]	75	?	IVE
3726.030[1]	4	4	II	3885.236[1]	8	8	I
3728.421[2]	250	4	IVE	3889.547[1]	8	10	I
3731.192[1]	5	5	II	3889.994[2]	300	5	IVE
3731.256[1]	5	5	II	3892.065[1]	4	8	IA
3732.560*[1]	?	10	II	3895.122[2]	125	4	IVE
3738.243[1]	4	8	IA	3896.808[2]	100	4	IVE
3742.228d?[1]	5	6	II	3898.279[2]	100	3	IVE
3743.981[1]	4	6	II	3898.971*[1]	?	15	I
3744.725[1]	5	5	II	3904.155*[1]	15	20	I

TABLE I—*Continued*

λ (I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
3907.294[2]	125	2	VE	3985.240[1]	5	5	II
3908.415[2]	125	4	IVE	3986.138[1]	5	5	II
3908.545[2]	100	4	IVE	3989.446[2]	30	.....	VE
3911.726[1]	4	5	II	3992.387[2]	125	4	IVE
3912.434[2]	300	4	IVE	3992.709[1]	4	4	II
3916.687[1]	5	8	I	3993.818[2]	200	tr	VE
3918.279[2]	200	5	IVE	3999.234[2]	500	10	IVE
3919.811[2]	100	1	VE	4003.768[2]	100	1	VE
3921.739[2]	100	?	VE	4005.231[*1]	?	25	I
3921.745[*1]	?	15	I	4011.290[1]	4	6	II
3923.108[2]	125	2	VE	4012.382[2]	300	6	IVE
3924.650[2]	60	5	IVE	4013.952[1]	4	6	II
3926.091[1]	8	8	I	4014.894[2]	125	tr	VE
3927.440[1]	6	8	I	4017.657[1]	6	8	I
3930.598[1]	4	6	II	4019.195[1]	4	6	II
3931.092[2]	125	4	IVE	4021.244[1]	5	5	II
3931.371[2]	100	2	IVE	4022.934[1]	4	4	II
3932.404[1]	3	5	II	4024.493[2]	60	1	IVE
3933.723[2]	?	5	IVE	4026.129[1]	2	5	IIA
3934.081[1]	15	15	I	4028.408[2]	150	4	IVE
3938.166[*1]	15?	15	I	4028.626[1]	3	6	IIA
3940.341[2]	100	3	IVE	4031.336[2]	150	6	IVE
3941.588[1]	10	8	I	4032.740[1]	2	5	IIA
3942.156[2]	125	8	IVE	4040.760[2]	300	10	IVE
3942.751[*2]	150	2	VE	4042.583[2]	200	5	IVE
3943.004[1]	15	10	I	4043.747[1]	4	5	II
3943.891[2]	100	4	IVE	4043.963[1]	6	6	II
3949.818[1]	30	20	I	4044.062[1]	6	6	II
3952.568[2]	125	5	IVE	4045.976[*1]	8?	5	I
	125	.....	VE	4046.342[2]	100	1	VE
3956.282[*2]	150	?	VE	4053.510[2]	100	7	IVE
3956.768[1]	20	20	I	4054.663[1]	5	5	II
3957.203[1]	15	15	I	4054.994[2]	50	3	IVE
3960.912[2]	125	6	IVE	4055.839[1]	25	20	I
3963.777[1]	3	5	II	4060.169[1]	8	8	II
3967.048[2]	100	3	IVE	4060.713[1]	20	15	I
3967.642[1]	5	5	II	4061.803[1]	8	8	II
3967.918[1]	4	4	II	4062.229[2]	60	1	VE
3971.686[2]	100	1	VE	4063.987[*1]	10?	10	I
3973.996[1]	10	12	I	4066.576[1]	10	10	I
3978.649[2]	125	2	VE	4066.916[1]	20	15	I
3980.894[2]	100	1	VE	4067.213[1]	5	5	II
3982.164[1]	15	15	I	4067.290[2]	50	.....	VE
3982.901[2]	60	tr	VE	4068.050[1]	6	8	I
3984.679[2]	100	tr	VE	4068.844[2]	75	tr	VE

TABLE I—*Continued*

λ (I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
4068.989[1]	6	15	IA	4146.233[2]	75	2	IVE
4070.098*[2]	15	.....	VE	4149.939[2]	60	.....	VE
4071.85*[2]	150	6	IVE		50	tr	VE
4073.485[2]	200	8	IVE	4150.143[1]	2	10	IA
4075.711[2]	150	3	VE	4151.721[1]	4	8	IA
4075.855[2]	125	4	IVE	4151.975[2]	200	4	IVE
4077.479[2]	75	tr	VE	4159.036[2]	50	1	IVE
4078.331[2]	60	tr	VE	4162.474[1]	3	5	II
4080.033[1]	8	10	I	4165.606[2]	200	1	VE
4081.224[2]	150	3	VE	4169.880[2]	30	.....	VE
4083.237[2]	200	tr	VE	4183.160[1]	4	4	II
4085.246[2]	100	1	VE	4185.518[1]	5	6	I
4086.373[1]	10	10	I	4186.598[2]	600	2	VE
4093.278*[1]	25	15	I	4186.821[1]	5	5	I
4093.963[2]	30	.....	VE	4188.384[1]	8	10	I
4095.122[1]	10	10	I	4193.105[2]	50	.....	VE
4095.449[1]	10	10	II	4194.106[1]	5	8	I
4096.093[1]	8	8	II	4196.338*[2]	75	?	VE
4098.144[1]	15	10	II	4197.995*[1]	?	10	II
4100.901[1]	20	12	I	4198.722[2]	75	1	VE
4101.775[2]	125	tr	VE		60	2	IVE
4105.00[2]	50	5	IVE	4202.947[2]	150	3	IVE
4107.425[2]	200	1	VE	4209.210[1]	10	10	I
4110.383[2]	60	tr	VE	4209.366*[1]	?	10	I
4111.40[2]	60	.....	VE	4214.040[2]	50	2	IVE
				4217.590[2]	30	.....	VE
4114.910[1]	20	15	I				
4115.376[2]	150	tr	VE	4221.632[1]	10	10	I
4115.656[1]	8	10	II	4222.604[2]	300	8	IVE
4117.013[2]	75	.....	VE	4222.887[1]	5	5	II
4118.146[2]	200	2	VE	4224.225[1]	4	6	II
				4227.748[2]	100	1	VE
4118.319*[1]	?	10	II	4231.749[2]	30	tr	VE
4120.835[2]	150	3	VE	4239.909[2]	200	3	VE
4123.875[2]	150	2	VE	4240.594[1]	6	6	II
4126.375[1]	15	10	I	4241.259[1]	3	6	IIA
4127.371[2]	150	4	IVE	4242.280d[1]	12	12	II
4128.904[1]	8	10	II	4243.799*[1]	8?	8	II
4130.707[2]	100	2	VE	4247.674[1]	2	6	IIA
4131.097[2]	100	2	VE	4248.672[2]	200	4	IVE
4132.447[1]	8	8	II	4253.369[2]	50	1	IVE
4133.801[2]	500	8	IVE	4254.371[1]	3	5	II
4135.109[1]	6	4	II	4254.690*[1]	8	15	I
4137.644[2]	400	10	IVE	4255.787[2]	60	2	IVE
4142.394[2]	150	2	VE	4258.326[1]	5	6	II
4142.719[1]	10	12	I	4262.810[1]	8	10	II
4144.992[2]	60	1	VE	4266.702[1]	5	8	II

TABLE I—*Continued*

λ (I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
4270.193[2]	60	3	IVE	4396.036[1]	30	20	I
4270.720[2]	50	.....	VE	4396.190[1]	15	15	II
4273.789[1]	3	6	IIA	4399.205[2]	60	2	IVE
4279.328[1]	10	12	II	4401.523[1]	15	20	I
4282.811[1]	3	5	II	4403.062[1]	15	15	II
4283.320[1]	2	6	IIA	4404.261[1]	2	5	IIA
4285.370[2]	30	1	IVE	4410.645[2]	30	.....	VE
4285.847[1]	4	10	IIA	4413.250*[1]	?	6	II
4287.005[1]	5	6	II	4415.774[1]	3	6	IIA
4289.933[2]	300	8	IVE	4416.622[1]	3	6	IIA
4290.289[1]	10	10	II	4418.782[2]	200	1	VE
4293.137[1]	12	15	I	4423.452[1]	30	25	I
4296.680[2]	200	5	IVE	4425.607[1]	2	4	IIA
4299.364[2]	60	3	IVE	4429.272[2]	100	tr	VE
4300.333[2]	60	2	IVE	4439.515[1]	15	15	I
4301.541[1]	8	12	I	4441.873[1]	2	4	IIA
4305.425[1]	10	10	I	4442.471[1]	5	5	II
4306.725[2]	100	3	IVE	4444.397[2]	60	tr	VE
4309.742[2]	50	2	IVE	4444.703[2]	75	tr	VE
4317.101[1]	8	8	II	4447.701[1]	15	15	I
4320.726[2]	60	2	IVE	4449.047[1]	2	5	IIA
4324.598[1]	25	25	I	4449.335[2]	200	?	VE
4325.308[1]	6	8	II	4449.365*[1]	?	15	II
4330.446[2]	30	1	IVE	4450.735[2]	75	1	VE
4330.939[1]	8	8	II	4460.212[2]	400	5	VE
4334.883*[1]	?	6	II	4461.138[2]	50	tr	VE
4336.253[2]	50	tr	VE	4463.411[2]	60	.....	VE
4337.776[2]	125	6	IVE	4467.319[1]	10	15	I
4339.317[2]	30	.....	VE	4471.240[2]	200	3	VE
4343.567[1]	20	20	I	4475.315[1]	4	4	II
4349.788[2]	100	2	IVE	4478.000[1]	4	10	IIA
4351.815[1]	12	15	I	4479.357[2]	50	.....	VE
4352.72*[3]	75	2	IVE		30	1	VE
4353.457*[1]	?	6	II	4479.985[1]	10	15	II
4364.502*[1]	?	6	II	4483.900[2]	100	tr	VE
4364.659[2]	125	2	IVE	4484.813*[1]	?	15	II
4368.879[1]	2	8	IIA	4486.909[2]	150	3	VE
4373.819[2]	50	tr	VE	4493.425[1]	3	8	IA
4375.93*[2]	60	1	VE	4497.614[1]	8	8	I
4380.698[1]	3	10	IIA	4497.849[2]	25	.....	VE
4382.173[2]	200	1	VE	4501.103[1]	12	15	I
4382.943d?[1]	6	10	II	4505.121[1]	6	10	I
4391.668[2]	250	6	IVE	4506.417[1]	25	25	I
4395.052[1]	3	5	II	4514.064[1]	6	8	II
4395.733[1]	12	10	II	4518.023*[1]	20	20	I
				4518.280[1]	3	4	II

TABLE I—*Continued*

λ (I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
4521.961[1]	10	10	II	4653.377[1]	2	5	IIA
4523.082[2]	125	2	VE	4654.31[3]	30	tr	VE
4527.338[1]	?	15	II	4667.371[1]	3	5	II
4527.354[*2]	200	?	VE	4669.52[3]	20	.....	VE
4528.479[2]	150	1	VE	4670.902[1]	8	8	II
4531.308d[*1]	15	20	I	4674.50[3]	5	10	IIA
4532.016[1]	6	8	II	4680.13[3]	25	.....	VE
4536.210[1]	3	4	II	4684.55[*1]	?	15	I
4539.755[2]	200	6	IVE	4684.62[3]	30	.....	VE
4540.632[1]	6	10	I	4688.90[3]	25	15	I
4545.452[1]	3	8	IIA	4690.71[1]	4	4	II
4546.064[1]	20	20	I	4690.83[1]	2	3	II
4548.888[1]	25	20	I	4691.96[*1]	?	5	II
4552.066[1]	4	12	IA	4696.53[3]	8	15	IIA
4553.060[1]	12	15	I	4700.62[3]	2	10	IIA
4560.27[3]	125	1	VE	4703.77[1]	4	8	IIA
4560.96[3]	60	.....	VE	4705.58[3]	10	15	I
4562.35[3]	400	3	VE	4706.49[3]	8	10	II
4565.242[1]	30	30	I	4707.03[3]	10	10	II
4565.85[3]	50	.....	VE	4707.27[3]	20	20	I
4570.096[1]	5	8	II	4714.00[3]	30	.....	VE
4570.645[1]	8	10	II	4715.07[3]	8	15	I
4572.28[3]	250	3	VE	4719.72[3]	4	8	IIA
4574.120[1]	3	5	II	4724.30[3]	8	12	I
4581.104[1]	4	4	II	4724.84[3]	20	20	I
4583.091[1]	8	12	I	4725.11[3]	20	.....	VE
4593.94[3]	200	tr	VE	4727.57[1]	4	6	II
4594.124[*1]	5	6	II	4733.92[3]	10	15	I
4600.233[1]	3	4	II	4734.67[3]	10	10	I
4602.763[1]	5	10	IA	4737.24[3]	60	1	VE
4606.42[3]	50	2	VE	4739.49[3]	25	.....	VE
4608.492[1]	20	20	I	4740.57[1]	4	8	IA
4610.474[1]	10	15	I	4743.25[3]	12	15	I
4615.195[1]	20	20	I	4744.76[3]	15	6	II
4620.047[1]	3	5	II	4747.07[*1]	?	20	I
4624.225[1]	6	10	II	4747.13[3]	20	.....	VE
4624.91[3]	60	.....	VE	4750.23[3]	5	8	I
4628.16[3]	500	5	VE	4750.85[3]	10	10	I
4632.329[*1]	40	30	I	4751.42[3]	5	6	II
4640.857[1]	8	8	II	4752.59[3]	10	8	II
4641.071[*1]	8	10	II	4757.82[3]	15	.....	VE
4643.175[1]	4	6	II	4757.91[*1]	?	10	II
4648.825[1]	4	5	II	4758.52[3]	4	5	II
4649.885[1]	10	12	I	4764.73[3]	5	6	II
4650.514[1]	15	15	I	4768.76[3]	12	.....	VE

TABLE I—*Continued*

λ (I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
4773.84*1	?	10	II	4870.17¹	2	4	IIA
4773.91³	50	.....	VE	4871.94¹	2	3	II
4775.06d?3	12	25	IA	4872.92³	6	5	II
4776.23³	8	8	I	4873.92*1	?	6	II
4776.47³	10	10	I	4874.35³	5	10	IA
4780.73¹	5	8	II	4881.52³	3	8	IA
4781.71³	5	8	I	4882.47³	40	1	VE
4782.22³	12	12	I	4889.57³	15	20	I
4784.76³	15	10	II	4892.87³	7	10	I
4786.53³	20	20	I	4893.25¹	2	6	IIA
4788.41³	20	15	I	4893.96³	15	.....	VE
4788.86¹	6	8	II	4894.75³	3	6	IIA
4801.36³	3	6	IIA	4896.92¹	1	7	IA
4803.09³	4	5	II	4897.08¹	8	6	II
4805.57³	3	5	II	4898.19³	5	5	II
4805.93³	30	25	I	4899.91³	30	10	II
4807.66³	10	15	I	4901.67³	10	12	I
4808.50¹	5	5	II	4904.85³	8	10	I
4810.38³	5	10	IA	4908.12³	3	4	II
4817.47³	8	8	II	4913.40³	2	6	IA
4820.02³	20	15	I	4914.09³	2	4	IA
4820.61³	10	10	I	4914.94³	8	.....	VE
4822.53³	50	40	I	4915.30³	20	15	I
4829.02³	4	4	II	4915.67³	20	8	II
4829.82³	4	6	I	4919.90³	5	10	IA
4834.02³	10	10	I	4920.80³	12	8	II
4835.42¹	3	6	IIA	4921.94¹	3	3	II
4836.66³	40	25	I	4924.04³	2	4	IIA
4837.43³	10	10	I	4924.27³	20	12	I
4838.42³	3	4	II	4924.56*1	.....	8	I
4838.93³	6	4	II	4930.56¹	2	6	IA
4842.28¹	4	5	II	4930.72³	5	5	I
4843.02³	10	12	I	4938.81³	2	4	IIA
4845.47³	50	40	I	4939.13³	20	12	I
4847.72*1	70	50	I	4943.47³	15	.....	VE
4849.51³	5	5	II	4944.61³	15	.....	VE
4849.89³	25	12	I	4948.67d³	7	10	I
4852.61³	8	6	I	4953.73³	3	3	II
4852.70¹	6	6	I	4954.03¹	4	3	II
4853.59³	5	5	II	4955.39³	4	7	I
4854.98³	4	5	II	4955.96³	4	6	II
4859.46³	20	15	I	4956.98¹	3	3	II
4861.72³	8	10	I	4958.24¹	2	4	IIA
4863.24¹	20	12	I	4965.18¹	4	4	II
4868.71¹	3	6	IA	4965.25¹	3	3	II

TABLE I—*Continued*

λ (I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
4966.38[3]	6	4	II	5055.97[3]	3	3	II
4970.10[1]	3	5	II	5063.92[3]	6	6	II
4970.64[3]	6	8	I	5065.88[3]	12	6	II
4971.48[3]	20	.....	VE	5071.49[1]	6	8	I
4971.66[1]	4	5	II	5071.73[1]	20	6	II
4971.90[1]	5	4	II	5074.67[1]	5	4	II
4972.20[1]	5	3	II	5075.20*[1]	?	4	II
4974.09[3]	4	6	I	5075.30[3]	20	.....	VE
4982.13[1]	2	4	IIA	5079.68[3]	75	.....	VE
4986.43d[3]	15	5	II	5080.48[3]	4	5	II
4987.52[1]	5	5	II	5083.58[1]	4	4	II
4988.68[3]	5	6	I	5084.18[3]	5	5	II
4990.65[1]	4	6	II	5084.81[1]	1	6	IIA
4992.39[3]	6	6	II	5091.76[3]	5	6	I
4994.61[1]	6	5	II	5097.29[1]	2	3	II
4995.26[1]	1	4	IIA	5099.40[2]	4	5	II
4998.12[3]	8	8	I	5107.18[1]	4	5	II
5001.49[1]	3	4	II	5107.47[1]	4	5	II
5003.27[1]	3	6	IIA	5111.59[3]	5	5	II
5005.69[1]	5	5	II	5112.69[3]	20	8	II
5009.07[3]	40	15	I	5115.03[3]	4	4	II
5009.44[1]	2	4	IIA	5115.23[3]	15	6	II
5011.76[3]	10	.....	VE	5115.62[3]	5	4	II
5012.47[3]	5	4	II	5117.17[3]	15	.....	VE
5013.75[3]	10	10	I	5120.69[3]	6	5	II
5016.49d[3]	8	10	I	5122.39d[3]	12	12	I
5021.42[3]	12	10	I	5122.68[3]	4	3	II
5022.85[3]	20	.....	VE	5125.00[3]	10	6	II
5028.31*[1]	8	10	I	5129.58[3]	35	20	II
5031.72[3]	6	5	II	5134.46[3]	4	4	II
5033.80[3]	4	4	II	5135.32[1]	2	3	II
5036.65[1]	6	8	I	5137.12[1]	4	2	II
5037.99[1]	2	4	IIA	5138.00[1]	4	6	II
5039.74[1]	4	4	II	5139.76[1]	3	5	II
5040.00[1]	2	5	IIA	5140.48[3]	4	4	II
5040.85[3]	25	12	I	5147.58[3]	8	.....	VE
5042.09[1]	4	4	II	5149.64[3]	8	8	I
5044.02[3]	25	.....	VE	5149.98[3]	15	4	II
5048.53[1]	1	5	IIA	5150.39[3]	6	6	I
5048.80[3]	12	10	I	5159.68[3]	40	12	II
5050.98[3]	4	4	II	5161.48[3]	40	8	II
5053.27[3]	4	5	II	5164.38[3]	4	4	II
5053.52[3]	5	5	II	5169.74[3]	4	8	IA
5054.15[3]	12	12	I	5174.58[3]	30	10	II
5055.77[3]	8	6	II	5177.73[1]	3	4	II

TABLE I—*Continued*

λ (I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
5178.68[3]	3	4	II	5264.18*[1]	6	6	I
5180.88[3]	8	10	I	5265.66[3]	15	.....	VE
5181.74[1]	3	3	II	5269.52[1]	6	6	II
5181.91[3]	8	8	I	5271.03[3]	5	5	II
5183.18[3]	4	5	II	5271.87d[3]	12	12	I
5187.38*[1]	?	6	II	5274.23[3]	75	.....	VE
5187.44[3]	60	.....	VE	5276.9[3]	2	4	IIA
5188.64[3]	12	5	II	5277.49[3]	3	8	IIA
5191.70*[1]	?	5	II	5281.35[1]	3	7	IIA
5191.76[1]	?	4	II	5286.79[3]	3	4	II
5194.74[1]	4	6	I	5290.92[3]	6	8	I
5198.68[1]	2	3	II	5294.04[3]	4	4	II
5200.13[1]	3	4	II	5296.58[3]	15	10	II
5200.43[1]	7	6	II	5298.23[3]	4	4	II
5201.39[3]	10	10	I	5303.31[3]	6	8	I
5202.48[1]	4	3	II	5308.30[1]	3	4	II
5202.58[1]	3	4	II	5308.52[3]	8	6	II
5203.27[1]	4	4	II	5313.91[3]	4	4	II
5204.27[1]	4	4	II	5314.38[3]	4	4	II
5204.72[1]	4	4	II	5314.83[1]	3	4	II
5205.13[3]	5	5	II	5314.99[1]	3	3	II
5207.34[1]	2	3	II	5317.58[3]	1	4	IIA
5208.91[1]	4	4	II	5328.05*[3]	20	10	I
5211.04[1]	3	4	II	5329.52[3]	4	3	II
5211.92d[3]	25	12	II	5330.56[3]	25	.....	VE
5216.40[3]	3	3	II	5335.72[3]	15	10	I
5221.94d[3]	3	5	II	5336.21[3]	8	7	I
5222.96[3]	4	4	II	5347.82[3]	4	3	II
5223.48[3]	20	8	II	5353.54[3]	50	1	VE
5229.76[3]	15	12	I	5355.20[3]	6	4	II
5230.13[3]	4	5	II	5355.61[3]	4	5	II
5230.84[3]	3	3	II	5357.21[3]	4	10	IA
5233.79[1]	3	6	IIA	5359.30[1]	2	4	IIA
5238.49[3]	4	6	I	5359.91d[3]	3	6	IIA
5243.06[3]	4	4	II	5363.36[3]	12	6	II
5244.48[3]	10	10	I	5369.12[3]	3	5	II
5245.26[1]	2	5	IIA	5371.60[1]	2	7	IIA
5245.89[3]	20	10	II	5379.96[3]	4	6	II
5249.19[3]	2	4	IIA	5382.61[3]	6	8	II
5249.59[3]	3	4	II	5386.35[3]	15	15	I
5250.10[1]	2	4	IIA	5391.89[3]	5	6	II
5250.45[1]	2	4	IIA	5393.42[3]	100	.....	VE
5254.82[3]	4	4	II	5395.28[3]	6	12	IA
5259.9[3]	2	4	IIA	5395.75[3]	4	4	II
5261.69*[1]	8	6	I	5397.65[3]	30	25	I

TABLE I—*Continued*

λ (I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
5399.08[3]	3	3	II	5537.52[4]	8	8	II
5399.61[3]	4	5	II	5544.65[4]	3	4	III
5401.20[3]	4	4	III	5548.81[4]	40	30	I
5409.28[3]	80	.....	VE	5551.40[4]	3	12	IIA
5409.41[*1]	?	5	II	5552.30[4]	2	8	IIIA
5411.83[3]	3	4	II	5554.36[4]	1	6	IIIA
5414.15[3]	4	5	II	5556.26d[*4]	60	10, 5	II
5418.71[3]	5	10	IA	5559.22[4]	6	5	II
5420.41[3]	20	10	II	5562.21[4]	2	8	IIIA
5423.47[3]	4	5	II	5564.26[4]	5	6	IIIA
5426.43[3]	3	10	IIA	5564.99[*4]	80	15	I
5427.29[3]	4	5	II	5565.97[4]	60	15	I
5430.29[3]	4	3	III	5572.23[4]	3	10	IIA
5433.37[3]	2	4	IIIA	5578.92[4]	4	5	II
5438.46[3]	3	8	IA	5582.73[*1]	20	30	I
5445.46[3]	4	10	IA	5584.72[4]	4	6	III
5446.20[3]	4	5	II	5588.33[4]	5	6	II
5449.28[3]	30	8	II	5590.52[4]	2	4	IIIA
5450.05[3]	3	4	III	5594.97[4]	15	6	II
5451.80[3]	3	3	III	5595.89[4]	40	8	II
5453.99[3]	3	4	II	5597.96[4]	10	8	IIIA
5456.40[3]	6	15	IA	5598.96[4]	7	12	IIA
5457.22[3]	4	7	IIA	5601.29[4]	100	25	II
5458.86[3]	3	10	IA	5604.39[4]	2	8	IIA
5460.09[3]	6	12	IIA	5606.47d[4]	8	12	II
5465.35d[3]	20	20	I	5609.44[4]	2	5	IIIA
5468.36[3]	15	5	III	5610.27[4]	20	1	VE
5472.29[3]	30	.....	VE	5610.93[4]	8	6	III
5473.53d[3]	10	12	I	5614.75[4]	20	12	I
5478.61[3]	8	10	I	5615.98[4]	3	6	IIIA
5482.00[3]	12	5	III	5620.38d[4]	3	8, 4	IIA
5491.10[3]	3	8	IA	5623.76[4]	2	8	IIA
5498.19[3]	20	10	II	5633.09[4]	8	20	IIA
5506.48[4]	4	5	III	5634.48[4]	2	6	IIA
5510.70[4]	5	8	III	5638.18[4]	8	12	I
5512.08[4]	150	3?	VE	5638.66[4]	3	8	IA
5512.13[*1]	?	10	I	5646.60[4]	3	4	III
5518.52[4]	10	.....	VE	5650.59[4]	12	20	II
5519.78[4]	1	4	IIIA	5655.17[4]	80	50	I
5522.50[4]	10	8	II	5659.81[4]	2	5	IIA
5523.01[4]	2	4	IIIA	5663.48[4]	3	5	III
5527.15[4]	4	6	III	5664.00[4]	12	7	III
5527.93[4]	2	6	IIA	5668.94[4]	40	?	VE
5535.25[4]	15	20	II	5669.97[*4]	125	15	I
5536.41[4]	1	3	IIA	5671.92[4]	5	8	I

TABLE I—*Continued*

λ (I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
5675.10⁴....	4	10	IA	5822.99⁴...	10	8	III
5677.76⁴....	50	12	I	5830.03d⁴..	4	15	IA
5682.77⁴....	2	5	IIA	5831.92⁴...	50	20	I
5688.48⁴....	2	4	IIIA	5834.25⁴...	4	6	II
5692.12⁴....	3	5	III	5835.84⁴...	50	10	II
5692.98⁴....	60	12	I	5838.13*⁴..	15	10	II
5695.88*⁴...	15	20	III	5839.36⁴...	10	15	I
5697.02⁴....	100	15	I	5843.10⁴...	2	4	IIIA
5699.24⁴....	100	25	I	5843.73*⁴..	6	6	II
5702.34d⁴...	6	8	III	5851.08d⁴..	8	10	II
5709.06d⁴...	1	6	IIIA	5853.34⁴...	6	6	III
5711.45⁴....	10	.....	VE	5853.68⁴...	6	8	III
5712.29⁴....	4	6	III	5854.85⁴...	1	6	IIIA
5718.42⁴....	3	10	IIA	5855.19⁴...	2	6	IIA
5719.09⁴....	100	20	I	5857.12⁴...	5	5	III
5719.55⁴....	3	8	IIIA	5858.19⁴...	4	5	III
5721.97⁴....	8	15	IIA	5859.37⁴...	6	5	III
5725.85⁴....	20	10	I	5862.50⁴...	60	12	I
5733.85⁴....	3	8	IIA	5871.61⁴...	20	15	I
5735.77⁴....	3	4	III	5872.94⁴...	2	4	IIA
5737.08⁴....	1	4	IIIA	5873.91⁴...	2	3	III
5743.52⁴....	60	15	I	5878.94⁴...	3	3	III
5746.48⁴....	2	4	IIIA	5892.48⁴...	3	5	III
5748.94⁴....	2	5	IIIA	5893.24⁴...	6	10	III
5758.24*⁴...	10	10	III	5900.66⁴...	4	8	IIA
5765.34⁴....	8	8	I	5901.33d⁴..	8	3	III
5768.94⁴....	20	.....	VE	5903.03⁴...	1	3	IIIA
5769.95⁴....	4	4	III	5906.00⁴...	10	10	II
5770.45⁴....	4	4	III	5909.88ᵗ...	30	12	II
5772.23⁴....	4	7	IIIA	5910.13ᵗ...	20	15	I
5772.89ᵗ....	15	10	I	5912.25⁴...	1	3	IIIA
5773.12ᵗ....	50	12	I	5912.88⁴...	20	10	II
5773.58⁴....	8	10	I	5914.84⁴...	8	7	II
5775.03⁴....	3	4	III	5919.43⁴...	1	5	IIIA
5782.80⁴....	2	5	IIIA	5920.40⁴...	20	8	II
5784.86⁴....	4	6	III	5924.05⁴...	4	6	II
5788.14⁴....	50	7	III	5926.28⁴...	40	30	I
5788.58⁴....	1	3	IIIA	5928.32⁴...	40	20	I
5794.79⁴....	1	4	IIIA	5929.84⁴...	6	6	III
5798.09⁴....	1	4	IIIA	5931.71⁴...	2	5	IIIA
5804.42⁴....	40	15	I	5932.17⁴...	4	6	III
5810.73⁴....	15	5	II	5937.69⁴...	30	12	I
5812.93*⁴...	80	15	I	5938.38⁴...	4	5	III
5820.38d⁴...	5	7	III	5940.84*⁴..	125	25	I
5820.80⁴....	1	4	IIIA	5942.66⁴...	10	20	I

TABLE I—*Continued*

λ (I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
5944.88[4]	8	5	III	6099.77[4]	3	8	IIA
5947.64[4]	6	6	III	6101.56[4]	1	6	IIIA
5948.19[4]	1	4	IIIA	6103.42[4]	1	4	IIIA
5950.60[4]	6	6	II	6114.69[4]	2	4	IIIA
5951.21[4]	2	3	III	6115.44[4]	2	5	IIIA
5960.17[4]	2	5	IIA	6117.71[4]	2	5	IIA
5963.35[4]	2	2	III	6118.87*[4]	4	6	II
5966.26d[4]	8	6	III	6119.79[4]	4	6	II
5972.80[4]	3	4	III	6123.66[4]	15	5	III
5975.90[4]	20	.....	VE	6124.31[4]	3	4	III
5975.97[1]	15	20	I	6131.13[4]	1	4	II
5979.39[4]	4	10	IIA	6133.61[4]	2	3	III
5988.79[4]	2	10	IIA	6142.92[4]	5	8	III
5989.37[4]	10	15	II	6146.42[4]	8	7	III
5992.64[4]	8	8	II	6147.85[4]	6	6	III
5997.77[4]	1	4	IIIA	6150.20[4]	1	4	IIIA
6000.17[4]	4	10	IIA	6151.73[4]	5	10	IIA
6005.85[4]	20	12	I	6155.05[4]	1	4	IIIA
6006.21[4]	6	10	I	6156.75[4]	2	4	IIIA
6006.80[4]	15	8	II	6158.93[4]	2	8	IIIA
6010.44[4]	2	4	IIIA	6162.14[4]	7	25	IA
6011.55[4]	2	3	III	6177.96[4]	4	7	IIA
6013.40[4]	40	20	I	6178.39[4]	4	7	IIA
6016.56[4]	6	15	IIA	6186.16[4]	15	4	III
6018.83[4]	2	5	IIIA	6187.91d[4]	3	5	II
6020.59[4]	2	5	IIIA	6192.27[4]	3	5	II
6024.19[4]	100	40	I	6195.27[4]	6	10	II
6027.16[4]	4	5	III	6195.55[4]	8	10	IIIA
6030.67[4]	1	4	IIIA	6202.11[1]	2	8	IIA
6031.25[4]	2	4	IIIA	6206.74[4]	2	4	IIIA
6036.62[4]	1	5	IIIA	6209.58[4]	5	7	III
6043.39[4]	60	1	VE	6211.05[4]	7	5	III
6047.39[4]	20	20	I	6223.23[4]	4	15	IIA
6057.42[4]	6	8	II	6228.24[4]	5	20	IA
6057.99[4]	15	10	I	6229.00[4]	15	10	IIIA
6059.32[4]	2	4	IIA	6237.45[4]	7	10	II
6066.72[4]	4	7	IIA	6238.71[4]	5	12	IIA
6069.46[4]	15	3	III	6241.91[4]	4	20	IA
6072.00[4]	12	10	II	6244.87[4]	1	10	IIA
6077.16[4]	2	6	IIA	6247.80[4]	1	8	IIIA
6081.27[4]	4	20	IIA	6253.62[4]	4	15	IIA
6086.62[4]	2	4	IIIA	6259.35[4]	1	5	IIIA
6089.65[4]	2	4	IIIA	6269.80d[4]	3	20	IIA
6093.19[4]	10	8	III	6272.05[4]	20	.....	VE
6098.34[4]	10	.....	VE	6273.71d[4]	4	12	IIA

TABLE I—*Continued*

λ(I.A.)	Intensities		Class	λ (I.A.)	Intensities		Class
	Arc	Furnace			Arc	Furnace	
6276.45d⁴	8	10	II	6522.55d⁴	2	10	IIA
6277.10⁴	3	10	IIA	6525.33⁴	2	7	IIA
6295.58⁴	30	50	I	6527.03⁴	2	3	III
6300.23⁴	25	30	I	6530.70⁴	4	6	II
6306.63⁴	8	15	IIA	6542.96⁴	1	7	IIA
6308.08⁴	3	10	IIA	6543.60⁴	2	10	IIA
6310.03⁴	30	30	I	6551.69⁴	15	25	I
6327.46⁴	2	6	IIA	6559.40⁴	2	5	IIA
6332.00⁴	5	20	IA	6573.65⁴	5	5	III
6335.39⁴	15	20	II	6574.45⁴	1	6	IIIA
6337.22⁴	6	10	II	6577.47⁴	2	6	IIA
6340.69*⁴	6	12	IIIA	6590.48⁴	1	3	IIA
6343.96*⁴	20	2	VE	6599.61⁴	3	5	II
6366.60⁴	1	3	IIA	6605.37⁴	4	8	IIA
6371.10⁴	10	1	IVE	6606.33⁴	10	20	IA
6372.48⁴	3	10	IIA	6606.87⁴	4	.....	VE
6372.99⁴	4	12	IIA	6622.98⁴	4	6	I
6386.16d⁴	6	3	III	6628.88*⁴	15	8	II
6386.86d?⁴	20	4	III	6641.13⁴	2	3	II
6390.32⁴	4	6	II	6643.15⁴	1	4	IIA
6393.02⁴	5	.....	VE	6651.40d⁴	10	4	III
6394.09⁴	1	4	IIIA	6652.75⁴	4	.....	VE
6396.26⁴	4	6	III	6655.47⁴	2	4	IIIA
6399.90d⁴	4	3	III	6661.41⁴	8	4	III
6411.68⁴	1	4	IIIA	6662.55⁴	2	6	IIIA
6424.47d⁴	3	15	IIA	6665.65⁴	10	10	II
6434.38⁴	12	40	IA	6679.84d⁴	8	8	III
6436.40⁴	10	15	II	6689.71⁴	3	6	IIA
6439.95⁴	5	15	IIA	6700.67⁴	20	3	III
6441.02⁴	2	8	IIA	6704.38⁴	40	40	I
6456.84⁴	1	4	IIA	6705.92*¹	3	5	III
6458.06⁴	50	60	I	6710.16⁴	3	5	III
6461.86⁴	5	8	II	6713.42⁴	5	5	III
6466.86⁴	5	.....	VE	6728.69⁴	8	8	II
6467.40⁴	20	40	IA	6729.55⁴	10	8	II
6468.46⁴	1	5	IIIA	6749.44⁴	4	5	III
6481.98⁴	3	8	IIA	6764.40d⁴	5	3	III
6485.97⁴	3	15	IIA	6767.65⁴	5	10	IIA
6488.68⁴	1	6	IIA	6775.57⁴	15	3	III
6490.97⁴	8	7	III	6778.23⁴	8	30	IA
6504.06d⁴	4	6	III	6780.72⁴	6	4	III
6507.74⁴	1	5	IIIA	6803.20⁴	4	6	III
6509.01⁴	5	20	IIA	6807.83⁴	15	4	III
6513.61⁴	5	.....	VE	6808.89⁴	8	10	II
6517.28d⁴	10	50	IA	6818.20⁴	8	20	IA

TABLE I—*Continued*

λ (I.A.)	Intensities		Class
	Arc	Furnace	
6826.43[4]	4	5	III
6847.27[4]	8	15	IIA
6894.55[4]	6	6	II
6924.77[4]	30	10	II
6932.12[4]	4	5	II
6934.02[4]	4	5	II
6939.40[4]	8	15	IA
6953.18[4]	4	4	II
6953.54[4]	4	4	II
6985.98[4]	15	15	I
6999.85[4]	10	15	I
7017.18[4]	4	3	II
7018.73[4]	4	3	II
7030.96[4]	3	3	II
7049.60[4]	2	2	II

NOTES—CERIUM

λ	
3030.232	Close to λ 3030.310 *Ce* II
3061.236	Klein λ 3061.215. May be close double
3063.109	Close to λ 3063.011 *Ce* II
3091.285	Blend in arc with λ 3069.292 *Ce* II
3169.150, 3169.181	Blend in arc
3181.640	Close to λ 3181.586 *Ce* II
3185.416	Blend *V* in furnace
3225.634	Close to λ 3225.680 *Ce* II
3227.136	Blend in arc with λ 3227.116 *Ce* II
3270.134	Blend in arc with λ 3270.129 *Ce* II
3286.039	Blend in arc with λ 3286.023 *Ce* II
3311.459	Blend in arc with λ 3311.495 *Ce* II
3316.539	Faint companion at λ 3316.586
3341.873	Blend *Ti* in furnace
3352.298	Blend in arc with λ 3352.280 *Ce* II
3365.842	Blend in arc with λ 3365.828 *Ce* II
3366.564	Blend in arc with λ 3366.552 *Ce* II
3393.585	Ratio of components 2:1
3433.131	Blend in arc with λ 3433.078 *Ce* II
3435.198	Blend in arc with λ 3435.206 *Ce* II
3437.823	Blend in arc with λ 3437.814 *Ce* II
3468.068	Blend in arc with λ 3468.119 *Ce* II
3468.986	Blend in arc with λ 3468.997 *Ce* II
3537.432	May be partly *Ce* II in arc

3546.182	Masked by carbon in furnace
3554.993	Masked by carbon in furnace
3560.795	Masked by carbon in furnace
3577.446	Masked by carbon in furnace
3654.977	Close to λ 3654.932 *Ce* II
3672.176	Blend in arc with λ 3672.166 *Ce* II
3706.932	Blend in arc with λ 3706.938 *Ce* II
3732.560	Blend in arc with λ 3732.580 *Ce* II
3746.401	Blend in arc with 3746.373 *Ce* II
3764.118	Masked by carbon in furnace
3781.621	
3782.524	
3801.526	
3803.098	
3808.118	
3815.832	
3834.555	
3848.600	
3853.166	
3854.194	
3854.326	
3878.373	
3882.453	
3898.971	Blend in arc with λ 3898.949 *Ce* II
3904.155	May be double. Furnace line slightly to violet of arc line
3921.745	Blend in arc with λ 3921.739 *Ce* II
3938.166	Blend in arc with λ 3938.162 *Ce* II
3942.751	Much enhanced in spark
3956.282	Blend *Ti* in furnace
4005.231	Blend *Fe* in arc. Furnace line not *Fe*
4045.976	May be partly *Ce* II in arc
4063.987	Blend in arc with λ 4063.913 *Ce* II
4070.098	Much enhanced in spark
4071.85	Close to *Fe*. λ from Bakowski
4093.278	Blend in arc with λ 4093.293 *Ce* II
4118.319	Close to λ 4118.146 *Ce* II
4196.338	Masked by carbon in furnace
4197.995	Blend in arc with λ 4198.000 *Ce* II
4209.366	Blend in arc with λ 4209.409 *Ce* II
4243.799	Blend in arc with λ 4243.763 *Ce* II
4254.690	Blend in arc with λ 4254.732 *Ce* II
4334.883	Blend in arc with λ 4334.869 *Ce* II
4352.72	Coincides with *Fe*
4353.457	Blend in arc with *Ce* II
4364.502	Blend in arc with *Ce* II
4375.93	Coincides with *Fe*
4413.250	Blend in arc with λ 4413.198 *Ce* II

4449.365	Blend in arc with λ 4449.335 *Ce* II
4484.813	Blend in arc with λ 4484.818 *Ce* II
4518.023	Furnace line partly *Ti*
4527.338	Blend in arc with λ 4527.354 *Ce* II
4527.354	Furnace line partly *Ti*
4531.308	Both components class I
4594.124	Blend V. May be partly *Ce* II
4632.329	Faint line to violet in arc
4641.071	Blend in arc with λ 4641.07 *Ce* II
4684.55	Blend in arc with λ 4684.62 *Ce* II
4691.96	Blend in arc with λ 4692.03 *Ce* II
4747.07	Blend in arc with λ 4747.13 *Ce* II
4757.91	Blend in arc with λ 4757.82 *Ce* II
4773.84	Blend in arc with λ 4773.91 *Ce* II
4847.72	*Ce* II close on red side in arc
4873.92	*Ce* II close on red side in arc
4924.96	May be impurity
5028.31	Blend in arc with *Ce* II
5075.20	*Ce* II close on red side in arc
5187.38	*Ce* II on red side in arc
5191.70	*Ce* II on violet side in arc
5261.69 5264.18	Close to strong *Ca* lines, but stronger lines of *Ca* multiplet are absent in *Ce* spectrum
5328.05	Coincides with strong low-temperature line of *Fe*, but no *Fe* lines appear in this region
5409.41	Blend in arc with λ 5409.28 *Ce* II
5465.35	Violet component faint
5512.13	Blend in arc with λ 5512.08 *Ce* II
5564.99	Relatively strong at low temperature
5582.73	*Ce* II on violet side in arc
5669.97	Relatively strong at low temperature
5695.88	Blend of three lines
5758.24	Blend of three lines
5812.93	Relatively strong at low temperature
5838.13	Blend in arc with *Ce* II
5843.73	Blend in arc with band head
5940.84	Relatively strong at low temperature
6118.87	Blend of three lines in arc; central line is class I
6340.69	Blend of three lines
6343.96	Furnace line may be *Ce* I
6628.88	Blend in arc with band head
6705.92	Blend in arc with *Ce* II

In the yellow and red, ionized cerium has few strong lines, but a large number of faint ones. While to the red of λ 5500, only 17 *Ce* II lines are given in Table I, many faint lines measured by Kiess in the arc have the characteristics of *Ce* II lines.

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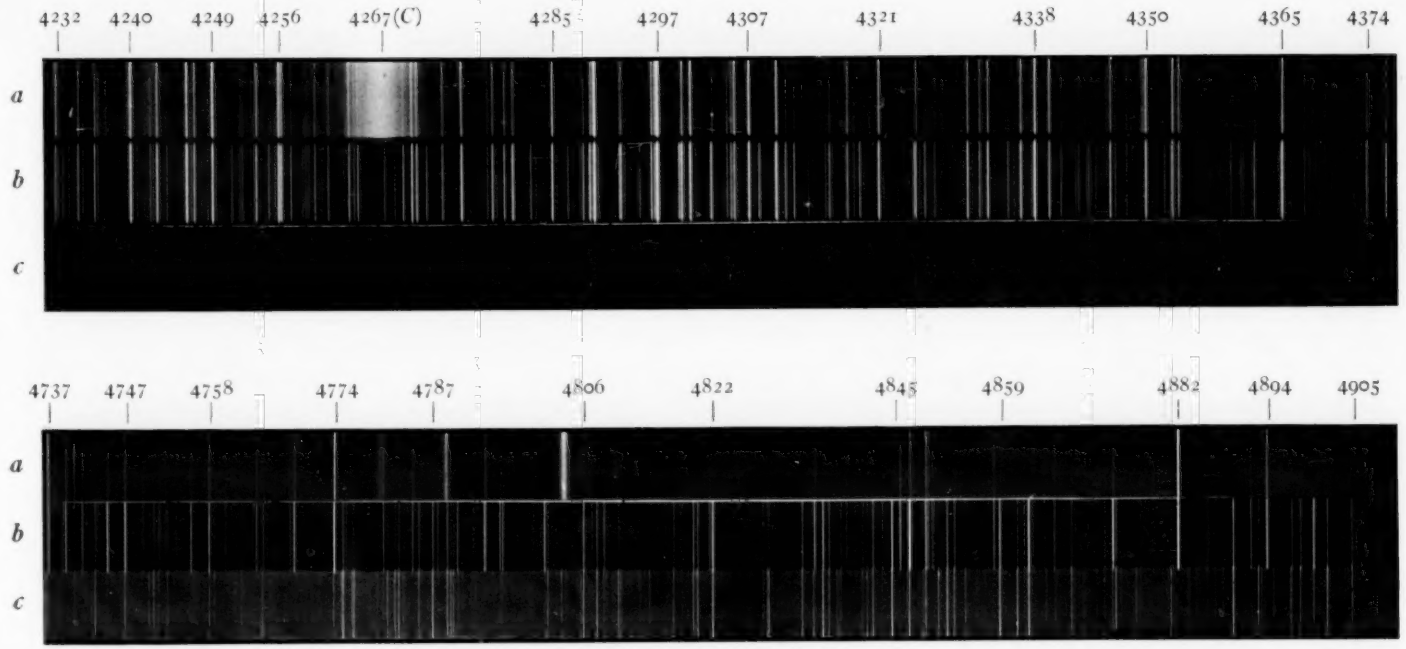
PLATE V



SPECTRUM OF CERIUM

a) Spark spectrum
b) Arc spectrum
c) Furnace spectrum

In appearance, the cerium lines are remarkably sharp. Reversals are difficult to produce, and no well-developed cases were observed, though at high temperature a slight widening of some lines may be noted. As far as could be judged with the moderate dispersion employed, the lines are single. At any rate they show no approach to the highly complex structure seen in the lines of lanthanum and praseodymium, between which cerium stands in order of atomic number.

The spectra reproduced in Plate V illustrate the different distributions of neutral and ionized lines near λ 4300 and λ 4800, respectively. In the blue, the arc spectrum is very similar to that of the spark, while in the green it is more like the furnace spectrum, a condition much accentuated at still greater wave-lengths. The furnace lines may be seen in both sections as present in the arc but absent from the spark.

PRASEODYMIUM

The study of praseodymium with reference to the temperature classification was conducted in the same manner as for cerium, except that a furnace temperature of 1900° C sufficed to bring out a large number of lines and was therefore used to select the more persistent low-temperature lines which make up class I. We again have numerous furnace lines which are faint in the arc and have not previously been measured. In the shorter wave-length region, the arc is less favorable for such lines than in the case of cerium, a very strong arc spectrum being required to give them a strength equal to that easily attained in the furnace. The rich spectrum of the arc is very similar to that of the spark, and indicates a highly ionized condition of the arc vapor. That a low ionization potential helps to bring about this condition is indicated by the strength in the furnace of many lines prominent in the arc and spark. Although much reduced in strength in the furnace, many of them retain sufficient intensity to be placed in class IIIE. They satisfy the test for ionized lines, however, as a mixture with caesium quenches these lines, while the neutral spectrum remains unchanged. At about λ 4500, the neutral lines become more prominent in the arc, and at greater wave-lengths they dominate the arc spectrum, as with cerium. We are not therefore dealing with a state of nearly complete ionization in the

arc, since it emits neutral lines in the green, yellow, and red with great intensity. There is, rather, a gradual diminution of the general intensity of the neutral spectrum with decreasing wave-length, until in the blue, where the ionized lines are very strong, the neutral lines have almost disappeared in the arc. The ionized spectrum in turn loses strength toward shorter waves, and in the near ultraviolet, for praseodymium near λ 3400 and for cerium near λ 3100, a powerful group of doubly ionized lines can be brought out in the spark. These have been noted by the writer[1] and will be discussed in a later publication.

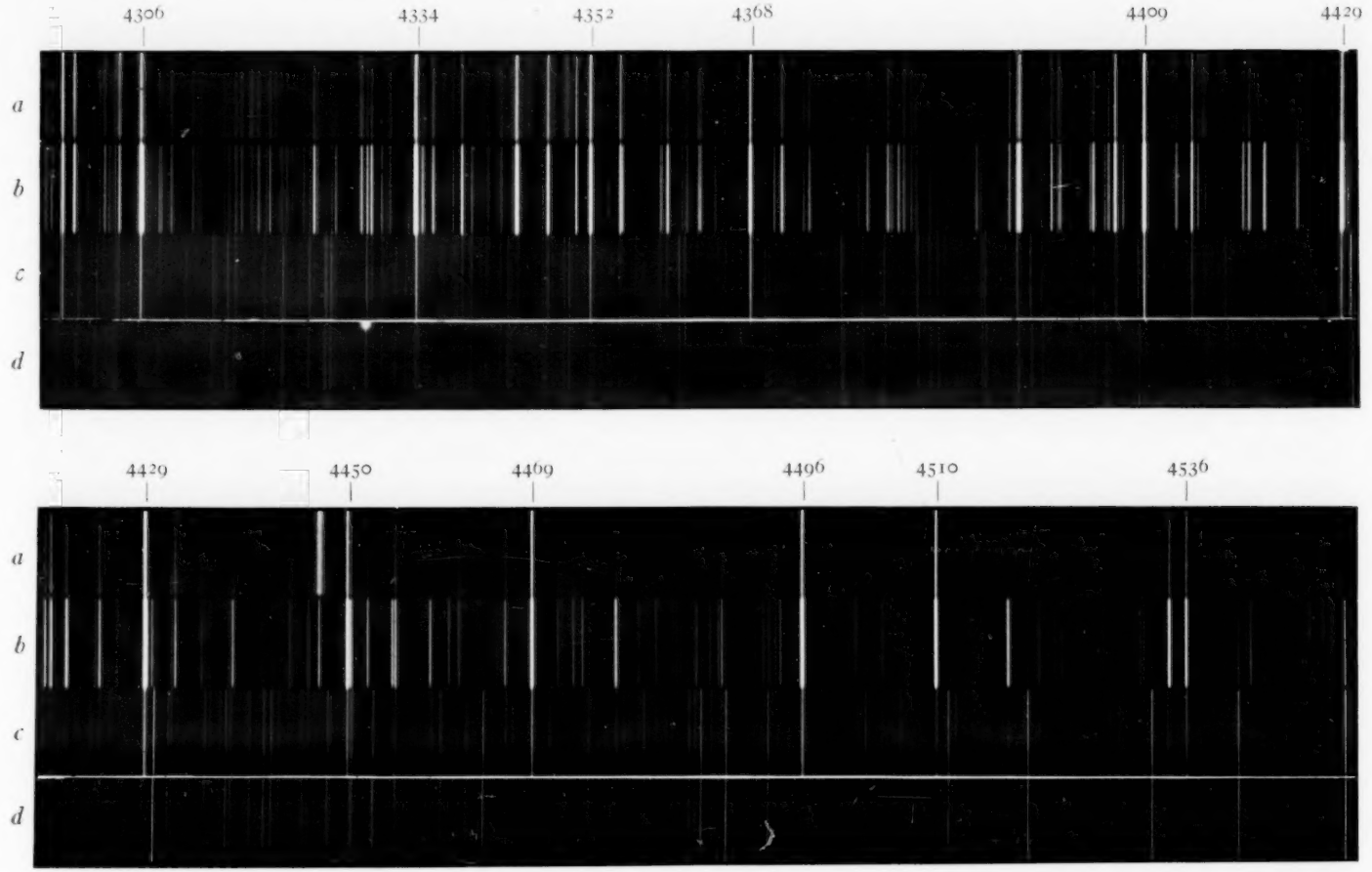
Praseodymium resembles lanthanum in the strength of many of its ionized lines in the furnace, and the ionization potentials of the two are not far apart. Rolla and Piccardi[2] give the ionization potential of lanthanum as 5.49 and that of praseodymium as 5.76 volts, while that of cerium, 6.91 volts, is distinctly higher.

The highly complex structure of the praseodymium lines is another feature possessed in common with lanthanum and to an even greater degree. A large proportion of the ionized, and some of the neutral, lines are made up of from three to six components, the spacing of these being in many cases unequal, in some cases gradually increasing toward the red, in others toward the violet. As this complexity was quite evident in the regular spectrograms, an attempt at better resolution was made by using the third order of a plane grating in the 30-foot spectrograph, with a scale of 0.61 A per mm. It was then clear that several types of resolution are present. There are patterns of varying numbers of unresolved components, which are apparently equally spaced, and two or three types each of patterns with spacing degraded either toward the violet or toward the red. The recurrence of similar patterns among lines in the same region suggests this as a means of selecting the members of multiplets. Measurements of some of the wider patterns showed a gradation in the spacing of a 6-component line, such as λ 4241.027 or λ 4272.267, from 0.05 A between the components at the red side

[1] Papers before the American Physical Society, *Physical Review*, Ser. 2, **30**, 366, 1927; **31**, 309, 1928.

[2] *Atti della R. Accad. dei Lincei, Classe di scienze fisiche, Rendiconti*, Ser. 6, **3**, 410, 1926.

PLATE VI



SPECTRUM OF PRASEODYMIUM

a) Spark spectrum
b) Arc spectrum
c) Furnace spectrum
d) Same, mixture of praseodymium and caesium

to about 0.025 A for those at the violet side. A wider type, with the largest interval on the violet side, showed a spacing of 0.62 A for this pair.

Praseodymium may be expected to supply excellent material for a study of the hyperfine atomic sublevels discussed by Meggers and Burns[1] in connection with the lanthanum spectrum. This will come after the assignment to multiplets, in which the similarity of patterns should be a guide. As both higher resolution and a sharpening of the components are needed to give measurements that will show the change of term values indicated by this structure, this paper indicates only the general character of pattern for each line, as nearly as it can be judged from the spectrograms. These data are in the final column of Table II. For each line clearly not single the apparent number of components is given. High-dispersion plates covered the region from λ 4100 to λ 4800, and were supplemented by data kindly supplied by Mr. H. E. White from plates made on Mount Wilson with the 75-foot spectrograph. The direction of the graduated spacing is indicated by "r" after the number when the red components are most widely separated, and by "v" when the spacing changes in the opposite direction.

Except for the additional column, the arrangement of Table II, containing 1018 lines, is similar to that of Table I. The sources of the wave-lengths are indicated by small numbers as follows:

1. King, furnace
2. Bertram,[2] arc (converted to I.A.)
3. Exner and Haschek, arc (converted to I.A.)

Plate VI reproduces a section of the praseodymium spectrum as given by the spark, arc, and furnace with praseodymium alone, and with a mixture of praseodymium and caesium. The spark spectrum, though of less general intensity, is seen to be much like that of the arc, while the stronger neutral lines of the furnace appear also in the arc spectrum. The group of very strong ionized lines appearing in the furnace with praseodymium alone is suppressed by the addition of caesium.

[1] *Journal of the Optical Society of America*, **14**, 449, 1927.

[2] *Zeitschrift für wissenschaftliche Photographie*, **4**, 16, 1906.

TABLE II

TEMPERATURE CLASSIFICATION OF PRASEODYMIUM LINES

λ (I.A.)	INTENSITIES		CLASS	NUMBER COMPONENTS
	Arc	Furnace		
3111.345[2]	30	.....	VE	.....
3121.591[2]	25 25	....	VE	.....
3129.207[2]	40	.....	VE	.....
3136.796[2]	20	.....	VE	.....
3151.513[2]	25	.....	VE	.....
3158.635[2]	30	.....	VE	.....
3163.717[2]	30 30	....	VE	.....
3164.817[2]	20	.....	VE	.....
3168.230[2]	75	.....	VE	.....
3172.290[2]	50	.....	VE	.....
3182.452[2]	20	.....	VE	.....
3191.416[2]	40	.....	VE	2?
3196.042[2]	50 20	.....	VE	.....
3199.056[2]	30	.....	VE	.....
3218.30[1]	4	6	II	.....
3219.551[2]	75	1	VE	.....
3225.21[1]	2	6	IIA	.....
3234.226[2]	20	.....	VE	2
3238.878[2]	15	.....	VE	.....
3244.32[1]	2	8	IIA	.....
3245.461[2]	25	.....	VE	.....
3248.77[1]	2	8	IIA	.....
3249.752[2]	10	.....	VE	.....
3253.17[1]	3	8	IIA	.....
3254.69[1]	2	6	IIA	.....
3258.96[3]	8	6	II	.....
3262.40[1]	3	5	II	.....
3264.33[3]	10	10	II	.....
3276.677[2]	12	.....	VE	.....
3295.546[2]	15	.....	VE	.....
3303.06[1]	?	5	II	.....
3306.78[1]	3	6	IIA	.....
3314.379[2]	12	.....	VE	2
3319.63[1]	4	6	II	.....
3324.555[2]	12	.....	VE	.....
3331.637[2]	7	5	II	.....
3341.469[2]	12	.....	VE	.....
3343.94[3]	8	4	II	.....
3353.46[1]	5	6	II	.....
3355.673[2]	75	2	VE	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
3363.98[3]	15	15	I	.....
3369.15[1]	3	6	IIA	.....
3372.508[2]	25	.....	VE	.....
3379.760[2]	12	.....	VE	.....
3381.37[1]	6	10	II	.....
3386.00[3]	15	15	I	.....
3386.59[1]	4	5	II	.....
3394.618[2]	75	2	VE	.....
3395.41[1]	4	5	II	.....
3414.77[3]	10	8	II	.....
3415.722*[2]	12	5	II	2
3417.99[1]	4	6	II	.....
3418.467[2]	50	.....	VE	3?
3419.247[2]	12	.....	VE	.....
3430.288[2]	50	1	IVE	.....
3432.07[3]	8	10	I	.....
3433.543[2]	40	.....	VE	2
3434.49[1]	4	4	II	.....
3437.61[3]	8	8	I	.....
3442.41[1]	2	4	IIA	.....
3444.32[1]	2	5	IIA	.....
3447.86[1]	4	6	II	.....
3448.208[2]	12	.....	VE	.....
3449.829[2]	15	.....	VE	2
3453.81[1]	3	7	IIA	.....
3461.22[1]	4	5	II	.....
3465.753[2]	30	.....	VE	.....
3466.23[1]	1	5	IIA	.....
3468.65[3]	6	5	II	.....
3469.02[1]	4	8	IIA	.....
3473.856[2]	30	.....	VE	3?
3474.43[3]	12	10	I	.....
3479.26[3]	8	8	II	.....
3482.24[1]	3	5	II	.....
3483.28[1]	2	5	IIA	.....
3487.584[2]	25	.....	VE	3?
3489.024[2]	15	.....	VE	.....
3491.46*[1]	?	4	II	.....
3491.944[2]	12	.....	VE	.....
3499.083[2]	50	.....	VE	4
3499.542[2]	25	.....	VE	3
3500.329[1]	6	10	I	.....
3503.080[2]	25	.....	VE	.....
3518.511[1]	6	10	I	.....
3522.975[1]	3	8	IIA	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
3532.814[1]	1	5	IIA	.....
3533.764[2]	25	.....	VE	.....
3539.920[2]	25	.....	VE	.....
3551.405*[1]	?	5	II	.....
3558.813[1]	4	6	II	.....
3563.486[1]	5	10	IA	.....
3574.964[2]	12	.....	VE	3
3577.473*[2]	30	?	V	3?
3582.972[1]	3	6	IIA	.....
3584.257[2]	40	.....	VE	.....
3591.209[1]	4	6	II	.....
3596.207[2]	20	.....	VE	.....
3605.068[2]	20	.....	VE	.....
3606.191[1]	3	5	II	.....
3611.963[2]	30	.....	VE	.....
3615.188*[2]	25	1	IVE	2
3616.687[2]	25	.....	VE	3
3617.643[1]	2	10	IA	.....
3621.088*[2]	60	.....	VE	5
3622.391[2]	25	.....	VE	2
3630.996[2]	40	.....	VE	.....
3635.312[2]	30	.....	VE	.....
3641.622[2]	40	.....	VE	2
3643.342[2]	15	.....	VE	.....
3645.563	60	.....	VE	.....
3645.673	75	.....	VE	.....
3646.317[2]	60	.....	VE	.....
3648.318[2]	15	.....	VE	.....
3654.618[1]	10	15	I	.....
3660.381[2]	30	.....	VE	4
3661.649[2]	25	.....	VE	.....
3662.463[1]	5	10	IIA	.....
3667.697[2]	20	.....	VE	.....
3668.461[1]	3	8	IIA	.....
3668.844[2]	150	4	IVE	.....
3675.520[1]	4	10	IIA	.....
3678.311[1]	4	10	IIA	.....
3681.667[1]	4	12	IA	.....
3687.055[2]	125	4	IVE	.....
3687.207[2]	60	2	IVE	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
3687.657[1]	4	12	IA	.....
3689.721[2]	20	.....	VE	.....
3693.606[1]	3	12	IA	.....
3695.457[1]	6	10	II	.....
3698.070[2]	25	.....	VE	3?
3698.731[1]	4	7	II	.....
3700.255[1]	4	7	II	.....
3701.821[2]	20	.....	VE	.....
3703.344[1]	8	8	II	.....
3706.772[2]	50	.....	VE	.....
3708.694[1]	3	3	II	.....
3711.083[2]	25	.....	VE	.....
	25	.....	VE	.....
3711.217[1]	6	10	I	.....
3714.048[2]	60	4	VE	3
3715.619*[1]	?	12	I	.....
3717.917[1]	4	6	II	.....
3720.228[2]	30	.....	VE	3
3721.682[1]	2	8	IIA	.....
3724.175[1]	2	8	IIA	.....
3724.391[1]	3	10	IIA	.....
3726.330[2]	15	.....	VE	.....
3729.412[2]	15	.....	VE	2
3730.600[2]	30	.....	VE	3
3732.479[1]	5	20	IA	.....
3733.012[2]	60	.....	VE	3
3734.027[1]	3	12	IA	.....
3734.411[2]	60	1	VE	3
3735.766[2]	40	1	VE	.....
3736.066*[1]	?	8	II	.....
3736.496[2]	40	.....	VE	3
3736.574*[1]	?	5	II	.....
3739.204[2]	100	5	IVE	.....
3741.014[2]	40	.....	VE	3
3744.000[2]	20	.....	VE	.....
3744.811[1]	5	12	IA	.....
3749.003[1]	2	8	IIA	.....
3750.384[1]	5	10	IA	.....
3751.005[2]	50	.....	VE	3
3756.141[1]	4	7	IIA	.....
3759.617[2]	75	4	IVE	.....
3760.075[2]	30	.....	VE	3
3760.964[1]	2	6	IIA	.....
3761.879[2]	250	8	VE	3
3764.810[2]	125	1	IVE	4
3768.388*[1]	2	8	IA	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
3768.939[2]	50	.....	VE	2
3769.710[2]	30	1	VE	2
3772.852[2]	100	3	VE	4
3773.468[1]	4	10	IA	.....
3774.073[2]	75	3	VE	2
3776.047[1]	10	6	II	.....
3777.649[2]	50	.....	VE	.....
3780.265[2]	15	.....	VE	.....
3780.66[3]	50	.....	VE	.....
3785.055[1]	4	6	I	.....
3785.501[2]	50	.....	VE	3
3786.901[2]	75	.....	VE	3
3789.716[1]	10	10	II	2
3792.539[2]	100	.....	VE	4
3794.770[1]	5	8	II	.....
3800.316[2]	200	10	VE	2
3804.766[2]	75	.....	VE	2
3809.17[3]	30	.....	VE	2
3816.162[2]	125	10	VE	2
3817.879[2]	30	.....	VE	2
3818.286[2]	125	10	VE	4
3821.81[3]	50	.....	VE	.....
3823.18[3]	75	.....	VE	3
3826.242[2]	100	4	VE	5
3830.716*[2]	125	?	VE	2?
3834.922[2]	30	.....	VE	3
3841.002[2]	60?	.....	VE	2?
3842.351[2]	60	.....	VE	3
3844.558[2]	60	.....	VE	4
3846.58[3]	125	.....	VE	4
3850.834[2]	150	8	VE	2
3851.611[2]	200	10	VE	3
3852.813[2]	150	5	VE	3
3854.909[2]	100	.....	VE	5?
3858.277[2]	30	.....	VE	.....
3861.265[2]	30	.....	VE	2
3865.44[3]	100	.....	VE	3
3867.55[3]	30	.....	VE	.....
3874.464[2]	25	.....	VE	.....
3876.188[2]	50	.....	VE	4
3877.203[2]	200	20	VE	6
3879.21[3]	25	.....	VE	2
3880.47*[3]	100	?	VE	2
3885.187[2]	75	10	IVE	4
3889.333[2]	75	12	IVE	5

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
3891.697[2]	12	.....	VE	3
3895.063	10	.....	VE	2
3896.863	10	.....	VE	3
3897.063	12	.....	VE	.....
3897.273	25	.....	VE	2
3898.839[2]	10	.....	VE	.....
3902.467[2]	25	.....	VE	3
3908.042[2]	150	20	IVE	5?
3908.423[1]	200	50	IIIE	3
3909.621[2]	8	.....	VE	.....
3910.578[1]	3	10	IIA	.....
3912.907[2]	125	25	IIIE	4
3913.525*[1]	5?	4	II	.....
3913.543[2]	15	.....	VE	.....
3914.781[2]	8	.....	VE	.....
3915.471[2]	10	1	IVE	2
3917.223	20	1	IVE	4
3918.856[2]	150	30	IIIE	4
3919.611[2]	25	3	IVE	2
3920.530[2]	15	6	IIIE	2
3924.139[2]	10	.....	VE	2
3924.507[1]	4	20	IA	.....
3925.465[2]	75	25	IIIE	3
3927.458[2]	30	12	IIIE	6?v
3927.723[2]	8	.....	VE	.....
3928.619[2]	10	.....	VE	6?v
3928.911[2]	10	.....	VE	6v
3929.264[2]	20	.....	VE	2?
3935.839[2]	25	10	IIIE	6?r
3938.311[2]	15	.....	VE	6?r
3940.143[2]	20	6	IIIE	6r
3945.423[1]	10	20	IA	.....
3945.669[2]	10	.....	VE	2
3946.218[1]	3	20	IA	.....
3947.642[2]	100	30	IIIE	6r
3949.444[2]	125	40	IIIE	6r
3953.533[2]	125	30	IIIE	6r
3956.769[2]	20	.....	VE	.....
3962.460[2]	40	15	IIIE	6?
3964.276[2]	40	20	IIIE	6?v
3964.837[2]	250	100	IIIE	6r
3965.268[2]	150	80	IIIE	6r
3966.576[2]	80	15	IIIE	6r
3971.161[2]	40	15	IIIE	6v
3971.698[2]	25	4	IIIE	2

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
3972.154[2]	100	40	IIIE	6r
3974.882[2]	15	.....	VE	.....
3982.069[2]	150	40	IIIE	6v
3982.507[2]	40	10	IIIE	6r
3989.709[2]	100	60	IIIE	6r
3991.889[2]	25	.....	VE	6?v
3992.191[2]	10	.....	VE	6?v
3994.364[1]	15	20	II	.....
3994.816[2]	200	80	IIIE	6r
3997.066[2]	40	20	IIIE	6r
3997.796[1]	5	10	IIA	.....
3997.983[2]	6	.....	VE	.....
3999.180[2]	20	.....	VE	5
3999.407[1]	4	8	IIA	.....
4000.193[2]	40	15	IIIE	6r
4000.478[2]	15	5	IIIE	.....
4002.003[1]	5	10	IIA	.....
4004.725[2]	25	15	IIIE	6?
4006.704[2]	8	2	IIIE	.....
4008.724[2]	75	30	IIIE	6v
4010.643[2]	12	1	IVE	.....
4011.532[1]	4	8	IIA	.....
4015.37[3]	40	15	IIIE	6?v
4016.746[2]	20	6	IIIE	5?
4021.004[2]	15	.....	VE	6?r
4022.211[2]	8	.....	VE	.....
4022.748[2]	15	.....	VE	.....
4023.737[1]	4	8	IIA	.....
4025.546[2]	?	5	II	3?
	20	.....	VE	
4026.839[2]	15	5	IIIE	6?
4027.667*[1]	?	10	II	.....
4029.041[2]	10	.....	VE	.....
4031.763[2]	50	30	IIIE	6r
4032.506[2]	15	.....	VE	6?r
4032.976[2]	15	.....	VE	6v
4033.854[2]	75	25	IIIE	6r
4038.157*[1]	?	8	II	.....
4038.189[2]	20	.....	VE	6?r
4038.478[2]	40	20	IIIE	6?v
4039.361[2]	30	20	IIIE	6r
4039.764*[1]	?	8	II	.....
4042.404[1]	5	10	II	.....
4044.827[2]	60	50	IIIE	6v
4046.636[2]	8	1	IVE	.....
4047.103[2]	15	1	VE	2

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
4051.159[2]	20	.....	VE	6r
4052.582[2]	10	.....	VE	.....
4054.848[1]	80	50	IIIE	6v?
4056.540[2]	80	30	IIIE	6v
4058.796[2]	15	8	IIIE	6?v?
4062.220[2]	8	.....	VE	.....
4062.504*[1]	?	10	II	.....
4062.821[2]	125	60	IIIE	6v?
4065.414[1]	6	15	IA	.....
4068.804[2]	15	.....	VE	2
4070.246[2]	10	1	IVE	2
4079.791[2]	30	1	VE	6?r
4081.017[2]	50	15	IIIE	6?r
4081.901[2]	50	.....	VE	6?r
4082.322[1]	4	8	IIA	.....
4083.338[2]	30	10	IIIE	.....
4086.570[1]	3	8	IIA	.....
4087.213[2]	15	.....	VE	4
4091.117[1]	5	6	II	.....
4094.971[2]	25	4	IVE	4
4096.345[2]	12	.....	VE	4
4096.828[2]	25	15	IIIE	6?v?
4098.412[2]	10	2	IVE	2
4100.744[2]	150	80	IIIE	6r
4105.733[2]	8	.....	VE	.....
4107.759[2]	10	.....	VE	2
4111.885[2]	25	5	IVE	5
4113.372[1]	6	6	II	.....
4113.873[2]	25	.....	VE	5
4118.481[2]	200	100	IIIE	6r
4129.156[2]	20	.....	VE	6?
4130.770[2]	40	5	IVE	6?
4132.230[2]	30	3	IVE	6r
4133.621[2]	15	.....	VE	.....
4140.574[2]	6	6	II	.....
4141.257[2]	80	30	IIIE	6r
4142.435[1]	10	8	II	.....
4143.134[2]	150	60	IIIE	6r
4146.544[1]	15	.....	VE	6r
4148.459[2]	15	10	IIIE	5?
4150.04[3]	10	.....	VE	3
4153.663[1]	6	6	II	.....
4156.522[2]	15	.....	VE	5
4164.192[2]	100	60	IIIE	6r
4169.450[2]	15	.....	VE	6v

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
4169.678[1]	5	15	IA	.....
4171.824[2]	40	25	IIIE	6r
4172.273[2]	50	30	IIIE	6r
4175.209[2]	15	.....	VE	6v
4175.646[2]	15	.....	VE	6v
4178.646[2]	20	.....	VE	6r
4179.421[2]	150	60	IIIE	6r
4182.498[1]	4	4	II	.....
4184.238[2]	8	.....	VE	5?
4185.155[2]	10	.....	VE	5?
4186.381[2]	8	.....	VE	.....
4189.346*[1]	?	8	II	.....
4189.518[2]	125	50	IIIE	6r
4191.618[3]	20	15	IIIE	6r
4201.187[2]	15	.....	VE	6r
4201.536[2]	10	.....	VE	3?
4206.743[2]	100	30	IIIE	6r
4207.810[2]	8	6	IIIE	5v
4208.310[2]	15	12	IIIE	6v
4211.858[2]	20	.....	VE	6r
4213.588[2]	10	.....	VE	5?
4214.478[1]	5	15	IA	.....
4216.786[1]	6	8	II	.....
4219.667[2]	15	.....	VE	6r
4222.986[2]	150	50	IIIE	6r
4223.210*[1]	?	8	II	.....
4225.337[2]	150	60	IIIE	6v
4225.544*[1]	?	10	I	.....
4230.677[1]	4	6	II	.....
4233.134[2]	10	.....	VE	.....
4236.211[2]	25	4	IIIE	6r
4236.644[2]	10	.....	VE	6?
4237.010[1]	8	8	II	.....
4240.045[2]	20	1	IVE	6r
4241.027[2]	60	8	IVE	6r
4243.537[2]	20	5	IIIE	6v
4247.670[2]	60	20	IIIE	6r
4249.085[2]	10	2	IVE	6?
4249.499[2]	15	.....	VE	6r
4250.416[2]	20	.....	VE	5r
4251.482[2]	20	.....	VE	6r
4252.637[1]	4	8	IIA	.....
4253.032[1]	4	8	IIA	.....
4254.430[2]	20	3	IVE	6v
4261.804[2]	15	1	IVE	6v

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
4262.314[2]	10	.....	VE	.....
4263.804[2]	30	4	IVE	6r
4265.490[1]	4	6	II	.....
4269.120[2]	10	.....	VE	.....
4271.768[2]	15	.....	VE	6?
4272.267[2]	80	20	IIIE	6r
4274.958[1]	4	8	IIA	.....
4280.105[2]	30	.....	VE	6r
4282.441[2]	60	8	IVE	6r
4285.535[1]	4	8	IIA	.....
4290.512*[1]	?	10	II	.....
4293.126[2]	15	.....	VE	6v
4293.586[2]	20	.....	VE	6r
4294.707[2]	20	.....	VE	6r
4297.758[2]	80	30	IIIE	6v
4298.924[2]	15	.....	VE	3
4303.508*[1]	?	10	II	.....
4303.595[2]	10	.....	VE	3
4305.769[2]	100	40	IIIE	6r
4306.096[2]	30	.....	VE	6v
4311.102[2]	10	.....	VE	6r
4313.153[1]	3	10	IIA	.....
4314.674[1]	5	8	II	.....
4317.823[2]	10	.....	VE	6r
4319.002[2]	10	1	IVE	.....
4320.358[1]	8	15	IIA	.....
4323.065[1]	10	10	II	.....
4323.523[2]	25	2	IVE	6v
4324.814[1]	8	10	II	.....
4328.912*[1]	?	8	II	.....
4328.977[2]	20	1	IVE	6v
4329.408[2]	25	2	IVE	6?v?
4333.913[2]	100	15	IVE	6r
4334.608[2]	15	2	IVE	6r
4338.690[2]	25	1	IVE	6v
4343.413[1]	2	5	IIA	.....
4344.321[2]	40	5	IVE	6v
4347.486[2]	30	8	IVE	6v
4349.663[1]	8	10	II	.....
4350.405[2]	20	1	IVE	.....
4351.850[2]	50	20	IIIE	6?v
4354.915[2]	15	1	IVE	.....
4359.107[2]	15	.....	VE	6r
4359.797[2]	30	5	IVE	6v
4360.966[1]	4	20	IIA	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
4361.541[1]	10	12	II	.....
4362.982[2]	10	.....	VE	6v
4363.197[2]	10	.....	VE	.....
4368.346[2]	150	40	IIIE	6v
4369.861[1]	5	8	II	.....
4370.809[2]	8	.....	VE	.....
4371.607[2]	40	.....	VE	6v
4373.808[2]	10	.....	VE	.....
4374.404[2]	20	.....	VE	6r
4377.642[1]	10	20	IIA	.....
4377.877[1]	4	6	II	.....
4380.329[2]	12	.....	VE	6r
4382.423[2]	20	.....	VE	6r
4382.80[3]	20	.....	VE	6v
4384.133[2]	20	.....	VE	6v
4385.455[1]	8	12	II	.....
4386.665[1]	4	5	II	.....
4387.587*[1]	3	8	IIA	.....
4392.087*[1]	6	10	II	.....
4392.465[1]	5	15	II	.....
4395.015[2]	15	.....	VE	.....
4395.807[2]	30	.....	VE	.....
4395.816*[1]	?	12	II	.....
4396.113[2]	40	.....	VE	6v
4397.121[1]	4	5	II	.....
4397.218[1]	3	8	IIA	.....
4399.329[2]	15	.....	VE	6r
4400.028[2]	15	.....	VE	6r
4400.260[2]	10	.....	VE	2?
4403.276[2]	10	.....	VE	.....
4403.600*[1]	?	8	II	.....
4403.622[2]	25	.....	VE	6v
4404.707*[1]	?	8	II	.....
4404.845*[1]	?	6	II	.....
4405.854[2]	80	10	IVE	6r
4408.174[1]	12	15	II	.....
4408.844[2]	200	100	IIIE	6v
4410.873[1]	4	6	II	.....
4412.172[2]	20	2	IVE	6r
4413.777[2]	50	10	IIIE	6v
4414.412[2]	10	.....	VE	.....
4417.209[1]	4	6	II	.....
4419.087[2]	25	.....	VE	6r
4419.656[2]	30	.....	VE	6v
4421.249[2]	40	5	IVE	6r

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
4423.684[1]	4	8	IIA	.....
4424.619[2]	25	2	IVE	6?
4429.248[3]	60	20	IIIE	.....
	100	20	IIIE	6r
4430.138[1]	12	40	IA	.....
4431.578[1]	6	8	II	.....
4431.910[1]	6	8	II	.....
4432.323[2]	25	.....	VE	6r
4437.465[1]	3	8	IIA	.....
4438.174[2]	20	.....	VE	6?v
4441.404[1]	3	12	IIA	.....
4442.913[1]	3	4	II	.....
4445.354[1]	2	6	IIA	.....
4445.893[2]	10	.....	VE	.....
4447.014[2]	20	.....	VE	6?v
4447.910[1]	6	12	IA	.....
4449.869[2]	150	30	IIIE	6r
4450.239[2]	40	10	IIIE	6v
4451.940[2]	20	.....	VE	6?v?
4452.529[1]	4	15	IIA	.....
4454.395[3]	30	5	IVE	6r
4458.333[2]	25	.....	VE	6r
4459.434[1]	5	15	IIA	.....
4463.762[1]	10	20	IIA	.....
4465.982[2]	25	.....	VE	6v
4466.785[1]	4	5	II	.....
4468.705[2]	150	40	IIIE	6v
4474.488[1]	4	10	IIA	.....
4477.274[2]	40	2	IVE	6r
4478.050[1]	4	6	II	.....
4478.638[1]	3	6	IIA	.....
4480.147[1]	6	12	IIA	.....
4481.413[2]	10	.....	VE	6?v
4484.714[1]	3	10	IIA	.....
4485.352[1]	6	8	II	6v
4486.030[1]	8	15	IIA	.....
4487.818[2]	20	.....	VE	6r
4488.191[2]	20	.....	VE	6?v
4488.630[2]	10	25	IA	.....
4492.437[2]	15	.....	VE	6v
4492.954[1]	10	15	II	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
4494.204[2]	20	.....	VE	6r
4496.433[2]	250	50	IIIE	6r
4502.845[1]	4	8	IIA	.....
4510.155[2]	100	20	IIIE	6v
4511.338[1]	4	8	IIA	.....
4511.437[1]	6	15	IIA	.....
4516.930[1]	5	5	II	.....
4517.594[2]	40	5	IVE	6r
4519.609[1]	20	40	IA	.....
4520.778[2]	8	.....	VE	5?
4523.194[1]	4	4	II	.....
4523.983[1]	3	5	II	.....
4528.047[1]	4	8	IIA	.....
4528.904[1]	5	8	II	.....
4529.95[3]	10	.....	VE	6v
4531.08[3]	20	.....	VE	6r
4531.491[1]	4	4	II	.....
4531.845[1]	2	6	IIA	.....
4532.325[1]	15	50	IA	.....
4533.915[1]	4	8	IIA	.....
4534.149[2]	60	5	IVE	6v
4535.917[2]	60	10	IIIE	6v
4541.043[1]	4	4	II	.....
4541.249[1]	15	20	I	.....
4542.528[2]	15	.....	VE	.....
4548.542[2]	15	.....	VE	6?v
4550.864[2]	15	.....	VE	6r
4552.247[1]	30	50	I	6?r
4552.823[1]	5	8	II	.....
4563.137[2]	30	1	IVE	5?
4563.825[1]	2	4	IIA	.....
4564.326[1]	4	4	II	.....
4566.85[3]	5	8	II	.....
4569.39[1]	2	5	IIA	.....
4569.630[1]	10	10	II	.....
4570.361[1]	12	15	II	.....
4570.551[2]	20	.....	VE	6v
4572.143[1]	15	25	I	.....
4574.922[1]	4	5	II	.....
4576.326[2]	20	.....	VE	6v
4577.015[1]	4	5	II	.....
4578.13[3]	25	.....	VE	6r
4581.559[2]	10	.....	VE	6?
4593.940[2]	10	1	IVE	2?
4597.66[3]	3	8	IIA	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
4598.93[3]	15	20	II	.....
4602.54[3]	4	20	IIA	.....
4605.19[3]	4	10	IIA	.....
4607.96[1]	4	4	II	.....
4611.67[1]	3	6	IIA	.....
4611.84[1]	2	5	IIA	.....
4612.06[3]	20	3	IVE	6?
4612.73[1]	2	5	IIA	.....
4617.11[1]	4	4	II	.....
4617.31[1]	2	4	IIA	.....
4617.70[3]	15	30	IA	2?
4618.24[1]	3	5	II	.....
4622.73[3]	5	8	II	.....
4624.03[3]	4	7	II	.....
4625.61[1]	2	5	IIA	.....
4628.75[3]	100	15	IIIE	6r
4632.26[3]	40	30	I	.....
4635.69[3]	50	50	I	.....
4639.53[3]	50	50	I	.....
4640.18[3]	15	15	I	.....
4643.51[3]	40	.....	VE	6r
4646.07[3]	30	.....	VE	6?v
4646.99[3]	15	20	I	.....
4651.51[3]	75	5	VE	6
4652.69[1]	2	4	IIA	.....
4655.98[1]	4	8	IIA	.....
4656.77[1]	3	5	II	.....
4658.37[1]	4	8	IIA	.....
4658.73[3]	20	20	II	.....
4660.91[3]	30	40	I	.....
4664.64[3]	20	.....	VE	6v
4664.74[1]	?	5	II	.....
4670.55[3]	10	15	II	.....
4672.09[3]	40	4	IVE	6v
4674.79[3]	30	30	I	.....
4675.03[1]	6	6	II	.....
4680.46[1]	3	4	II	.....
4682.69[1]	2	10	IIA	.....
4684.93[3]	20	.....	VE	6r
4687.82[3]	60	60	I	.....
4689.55[3]	15	20	II	.....
4690.58[3]	5	5	II	.....
4691.80[3]	4	4	II	.....
4692.65[3]	8	12	II	.....
4695.78[3]	50	50	I	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
4699.56[3]	5	10	IIA	.....
4707.52[3]	20	.....	VE	6r
4707.97[3] }	80	4	IVE	6r
4708.17[3] }				
4709.47[3]	40	40	I	.....
4711.82[3]	8	10	II	.....
4713.08[3]	30	40	I	.....
4714.11[3]	30	30	I	.....
4724.78[3]	2	15	IIA	.....
4728.63[3]	15	.....	VE	6v
4730.72[3]	60	60	I	.....
4733.40[1]	1	10	IIA	.....
4733.77[3]	6	10	II	.....
4734.04[1]	4	5	II	.....
4734.17[3]	25	.....	VE	6r
4736.72[3]	100	100	I	.....
4741.52[3]	12	25	IIA	.....
4744.18[3]	20	25	I	.....
4744.93[3]	40	2	VE	6r
4746.94[3]	40	.....	VE	6v
4756.13[3]	40	.....	VE	6r
4758.05[3]	30	.....	VE	6r
4762.73[3]	20	.....	VE	6v
4764.44[3]	6	20	IIA	.....
4765.22[3]	20	.....	VE	6r
4766.90[3]	12	.....	VE	.....
4767.80[3]	20	40	IA	.....
4774.53[3]	2	20	IIA	.....
4775.41[3]	8	12	II	.....
4783.35[3]	25	4	VE	6r
4788.26[3]	6	20	IA	.....
4795.27[3]	8	8	II	.....
4801.10[3]	15	.....	VE	.....
4801.50[3]	8	15	IIA	.....
4808.17[3]	15	50	IA	.....
4814.33[3]	12	.....	VE	.....
4821.95[3]	6	6	II	.....
4822.98[3]	40	2	IVE	6v
4825.82[3]	4	12	IIA	.....
4827.24[3]	5	10	IIA	.....
4830.22[3]	6	25	IIA	.....
4832.09[3]	20	.....	VE	6r
4837.02[3]	20	.....	VE	6r
4840.47[3]	4	30	IIA	.....
4848.52[3]	20	.....	VE	6r

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
4853.69[3]	12	40	IA	.....
4856.07[3]	2	15	IIA	2
4857.36[3]	10	15	II	.....
4859.00[3]	12	.....	VE	6r
4859.94[3]	4	10	IIA	.....
4862.00[3]	3	7	IIA	.....
4863.12[3]	1	4	IIA	.....
4865.22[3]	15	.....	VE	.....
4869.33[3]	10	12	II	.....
4875.04[3]	4	20	IIA	.....
4877.81[3]	40	.....	VE	6v
4882.22[3]	15	60	IA	2?
4884.45[3]	8	12	II	.....
4886.02[3]	5	.....	VE	.....
4889.65[3]	5	10	IIA	.....
4890.27[3]	12	.....	VE	.....
4896.12[3]	25	40	IA	.....
4899.92[3]	6	.....	VE	.....
4903.38[3]	8	30	IA	.....
4904.43[3]	4	8	IIA	.....
4906.97[3]	40	40	I	.....
4912.62[3]	12	.....	VE	.....
4914.02[3]	80	80	I	.....
4914.71[3]	4	8	IIA	.....
4915.41[3]	8	15	IIA	.....
4916.99[3]	5	7	II	.....
4924.59[3]	100	100	I	.....
4924.80[3]	10	20	IIA	.....
4925.32[3]	8	15	IIA	.....
4925.61[3]	15	.....	VE	5?
4932.20[3]	6	40	IIA	.....
4935.98[3]	40	30	I	.....
4938.39[3]	8	30	IIA	.....
4938.90[3]	8	15	IIA	.....
4939.73[3]	100	60	I	.....
4940.31[3]	60	60	I	.....
4947.19[3]	4	12	IIA	.....
4951.34[3]	150	100	I	.....
4956.02[3]	8	30	IA	.....
4956.58[3], 4956.70[3]	20	.....	VE	6?
4960.27[3]	15	40	IA	.....
4961.06[3]	4	7	II	.....
4967.88[3]	6	6	II	2
4970.97[3]	6	8	II	.....
4974.91[3]	20	30	I	.....
4975.73[3]	40	50	I	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
4976.37[3]	40	50	I	.....
4979.09[3]	4	8	IIA	.....
4989.26[3]	20	.....	VE	5?
5002.43[3]	12	.....	VE	.....
5007.60[3]	4	40	IA	2?
5018.55[3]	40	50	I	2
5019.72[3]	60	40	I	.....
5026.93[3]	80	60	I	.....
5028.98[3]	4	12	IIA	.....
5033.37[3]	20	40	IA	.....
5034.37[3]	20	.....	VE	.....
5037.44[3]	12	.....	VE	6?
5043.82[3]	30	40	I	.....
5045.51[3]	60	30	I	.....
5053.40[3]	50	40	I	.....
5063.39[3]	5	25	IIA	.....
5075.68[3]	15	.....	VE	6?
5076.69[3]	2	6	IIA	.....
5084.45[3]	2	5	IIA	.....
5087.12[3]	40	30	I	.....
5110.39[3]	60	.....	VE	.....
5110.77[3]	60	.....	VE	.....
5117.28[3]	4	4	II	.....
5129.53[3]	40	2	IVE	.....
5133.42[3]	80	60	I	.....
5135.12[3]	20	.....	VE	.....
5139.82[3]	20	25	I	.....
5147.46[3]	4	20	IA	.....
5149.87[3]	8	12	II	.....
5151.34[3]	4	5	II	.....
5152.24[3]	30	.....	VE	6r
5156.49[3]	15	.....	VE	5?
5159.21[3]	3	4	II	.....
5161.74[3]	20	.....	VE	2?
5168.32[3]	5	25	IA	.....
5173.93[3]	60	2	IVE	.....
5177.37[3]	8	15	IIA	.....
5183.87[3]	15	.....	VE	.....
5191.36[3]	30	.....	VE	5?
5194.45[3]	30	30	I	.....
5195.15[3]	20	.....	VE	.....
5195.33[3]	30	.....	VE	.....
5195.49[3]	30	60	IA	2
5206.57[3]	20	.....	VE	.....
5207.92[3]	10	.....	VE	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
5219.07[3]	20	2	IVE	.....
5220.13[3]	50	2	IVE	.....
5228.00[3]	20	30	I	.....
5249.84[3]	4	15	IIA	.....
5251.79[3]	12	.....	VE	5?
5259.68[3]	80	2	VE	.....
5263.83[3]	20	2	IVE	.....
5268.83[1]	1	25	IIA	.....
5269.03[3]	1	15	IIA	.....
5285.60[3]	15	15	I	2
5289.29[3]	6	20	IIA	.....
5291.93[3]	60	.....	VE	6v
5292.12[3]				
5292.23*[1]	?	8	II	2
5292.63[3]	30	1	IVE	.....
5298.08[3]	15	.....	VE	.....
5311.12[3]	5	.....	VE	.....
5312.33[3]	20	.....	VE	6v
5313.63[1]	2	20	IIA	.....
5316.62[3]	3	10	IIA	.....
	1	4	IIA	.....
5321.05[3]	5	.....	VE	.....
5322.67[1]	2	20	IA	.....
5322.77[1]	60	2	VE	.....
5331.48[3]	4	.....	VE	.....
5343.89[3]	4	.....	VE	.....
5352.42[3]	30	.....	VE	3?
5359.01[3]	6	20	IIA	.....
5372.40[3]	4	12	IIA	.....
5374.26[3]	3	5	II	.....
5381.31[3]	60	.....	VE	.....
5388.82[3]	2	20	IIA	3
5395.89[3]	15	50	IIA	3
5400.97[3]	5	4	II	.....
5402.60[3]	15	8	II	3
5410.55*[3]	10	2	II	5?
		.....	VE	
5411.59[3]	20	1	IVE	.....
5413.20[3]	60	3	IVE	.....
5413.42[3]		6	IVE	.....
5418.85[3]	4	8	IIA	.....
5424.56[1]	2	10	IIA	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
5427.30[3]	12	8	II	.....
5432.93[1]	10	50	IA	2?
5437.40[3]	10	10	II	3?
5457.07[3]	6	6	II	.....
5460.29[3]	15	30	IA	.....
5462.41[3]	2	3	II	.....
5469.70[3]	8	5	II	.....
5469.91[3]	12	6	II	.....
5479.75*[3]	40	60	II	2
5481.76[3]	6	25	IA	.....
5485.50[3]	5	3	II	.....
5486.62[3]	3	4	II	.....
5487.45[3]	15	12	II	.....
5487.57[3]				
5488.94[3]	5	5	II	.....
5490.60[3]	8	6	II	.....
5496.24[3]	3	10	IIA	2
5497.28[3]	12	4	II	2
5501.52[3]	8	6	II	.....
5504.74[3]	2	3	II	.....
5509.14[3]	30	.....	VE	.....
5513.61[3]	12	.....	VE	.....
5516.24[3]	4	4	II	.....
5517.69[3]	2	5	IIA	.....
5520.34[3]	8	3	II	.....
5522.80*[3]	40	6	II	.....
		6	II	.....
5524.14*[3]	4	15	IIA	.....
	20	3	II	.....
5530.20[3]	4	15	IIA	.....
5531.18[3]	15	10	II	.....
5535.18[3]	12	.....	VE	.....
5538.37[3]	12	10	II	.....
5544.99[3]	8	.....	VE	.....
5562.01[3]	15	6	II	5?
5565.51[3]	4	3	II	.....
5571.81[3]	6	.....	VE	.....
5578.79[3]	2	4	IIA	.....
5594.91[3]	15	12	II	.....
5605.63[3]	20	.....	VE	.....
5610.20[3]	8	.....	VE	.....
5620.28[3]	10	5	II	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
5621.88[3]	12	.....	VE	.....
5623.05[3]	25	.....	VE	.....
5624.44[3]	15	.....	VE	.....
5633.04[3]	3	3	II	.....
5638.77[3]	12	.....	VE	5?
5640.34[3]	4	4	II	.....
5643.4[3]	4	2	II	3?
5650.64[3]	3	3	II	.....
5653.08[3]	2	10	IIA	.....
5654.24[3]	4	.....	VE	.....
5659.87[3]	5	.....	VE	.....
5661.59[3]	8	2	II	2
5668.48[3]	40	15	II	5?
5669.54[3]	5	.....	VE	.....
5670.00*[3]	6	2 /	II / VE	.....
5681.88[3]	6	.....	VE	.....
5687.47[1]	2	20	IA	.....
5688.44[3]	20	2	IVE	.....
5695.48[3]	4	5	II	.....
5704.43[3]	6	6	II	.....
5707.62[3]	60	20	II	5
5713.84[3]	2	4	IIA	.....
5719.09[3]	8	.....	VE	.....
5722.22[1]	1	6	IIA	.....
5731.88[3]	4	.....	VE	.....
5756.17[3]	20	.....	VE	.....
5760.20[3]	6	6	II	.....
5779.27[3]	60	40	II	.....
5785.37[3]	8	.....	VE	3?
5786.21[3]	8	.....	VE	.....
5791.44[3]	12	.....	VE	.....
5792.94[1]	5	4	II	.....
5815.22[3]	15	.....	VE	.....
5815.38[3]	8?	2	II	.....
5818.62[3]	6	.....	VE	.....
5820.67[3]	12	8	II	2
5821.34[1]	8	8	II	2
5823.73[3]	25	1	VE	2
5835.14[3]	25	40	I	.....
5845.01[3]	10	.....	VE	5?
5847.09[3]	10	.....	VE	2
5850.69[3]	8	.....	VE	3?
5859.70[3]	15	1	VE	.....
5867.53[1]	2	3	II	.....
5868.84[3]	15	.....	VE	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
5874.79[3]	4	6	II	.....
5878.12[3]	12	8	II	2
5879.28[3]	15	15	II	.....
	12	.....	VE	.....
5884.7[3]	6	8	II	.....
5892.30[3]	4	.....	VE	.....
5904.52[3]	4	.....	VE	.....
5915.36[3]	4	6	II	.....
5916.03[3]	4	5	II	.....
5920.82[3]	25	30	I	.....
5930.71[3]	6	3	II	.....
5935.49[1]	3	10	IIA	.....
5939.96[3]	25	.....	VE	.....
5940.79[3]	4	.....	VE	.....
5941.71[1]	6	6	II	.....
5949.79[3]	8	6	II	3?
5951.32[3]	6	.....	VE	.....
5956.33[1]	2	5	IIA	.....
5956.64*[3]	15	.....	VE	.....
		2	II	.....
5959.29[3]	4	3	II	3?
5962.25[3]	6	12	IIA	.....
5963.08[3]	12	10	II	.....
5967.87[3]	20	.....	VE	.....
5968.35[1]	5	5	II	.....
5976.88[3]	4	4	II	2
5978.88[3]	5	5	II	.....
5981.23[3]	15	.....	VE	.....
5986.13[3]	15	6	II	3?
5987.18[3]	5	3	II	.....
6006.38[3]	12	.....	VE	.....
6008.61[1]	4	5	II	.....
6016.49[3]	6	.....	VE	.....
6017.80[3]	25	.....	VE	.....
6019.92[1]	15	5	II	5?
6025.74[3]	20	.....	VE	.....
6046.68[3]	12	.....	VE	.....
6049.31[3]	15	15	II	.....
6050.94[1]	4	4	II	.....
6055.15[3]	100	80	II	3?
6075.17[1]	8	8	II	5?
6087.51[3]	12	.....	VE	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
6096.34[3]	4	1	II	3?
6100.69[3]	1	12	IIA	2?
6105.52[1]	4	4	II	3?
6108.54[1]	1	6	IIA	.....
6109.06[3]	6	20	IIA	.....
6114.41[3]	8	.....	VE	.....
6116.68[1]	1	8	II	.....
6118.02[1]	10	10	II	5?
6122.23[3]	10	5	II	2
6141.55*[3]	10	5	II VE	5?
6142.42[1]	1	6	IIA	.....
6148.26[3]	7	4	II	.....
6161.21[3]	50	tr	VE	.....
6162.19[3]	5	.....	VE	.....
6165.31[3]	6	4	II	2
6165.96[3]	60	tr	VE	.....
6174.31[1]	4	6	II	.....
6182.36[3]	5	.....	VE	.....
6187.97[1]	3	5	II	.....
6191.48[1]	8	30	IIA	3?
6210.58[3]	4	4	II	.....
6212.72[3]	15	10	II	5?
6218.10[3]	4	2	II	.....
6236.86[3]	6	2	II	3?
6241.09[1]	10	4	II	5?
6244.40[3]	5	.....	VE	.....
6251.01[1]	2	6	IIA	3?
6262.43[1]	2	10	IIA	.....
6262.62[3]	3	.....	VE	.....
6278.72[3]	6	.....	VE	.....
6281.37[3]	50	.....	VE	.....
6287.05[3]	2	3	II	2
6289.11[1]	10	10	II	5?
6302.45[3]	20	6	II	.....
6304.10[3]	8	12	II	.....
6305.32[3]	4	.....	VE	.....
6322.36[3]	40	15	II	5?
6343.94[3]	15	8	II	3?
6346.75[1]	5	5	II	2
6347.17[3]	6	.....	VE	.....
6347.73[1]	5	5	II	.....
6351.00[3]	15	15	II	3?
6357.22[3]	15	20	II	3?
6359.10[3]	50	30	II	.....
6377.7[3]	5	4	II	.....

TABLE II—*Continued*

λ (I.A.)	Intensities		Class	Number Components
	Arc	Furnace		
6378.65[3]	10	10	II	.....
6389.65[3]	7	7	II	.....
6392.1[3]	8	6	II	3?
6393.20[3]	30	30	II	.....
6398.05[3]	6	.....	VE	.....
6404.34[1]	8	4	II	5?
6410.66[1]	10	8	II	.....
6411.30[3]	40	40	II	2
6413.76[3]	10	.....	VE	.....
6415.5[3]	8	8	II	3?
6419.64[1]	2	8	IIA	.....
6421.52[1]	4	6	II	3?
6429.67[3]	7	.....	VE	.....
6431.86[3]	8	.....	VE	.....
6440.69[1]	8	8	II	3?
6453.44[3]	10	5	II	3?
6456.17[1]	10	10	II	2
6462.7[3]	8	10	II	.....
6478.0[3]	12	.....	VE	.....
6486.59[3]	60	50	I	.....
6491.81[3]	40	30	I	.....
6493.54[1]	8	15	IIA	.....
6494.93[1]	5	5	II	.....
6497.2[3]	5	3	II	.....
6500.78[3]	15	12	II	.....
6504.16[3]	5	4	II	.....
6517.2[3]	4	6	II	.....
6540.5[3]	15	50	IIA	5?
6553.34[1]	4	8	IIA	3?
6560.75[1]	3	10	IIA	.....
6564.67[3]	6	.....	VE	.....
6566.77[3]	15	.....	VE	.....
6571.06[1]	3	4	II	.....
6578.02[1]	4	4	II	.....
6595.50[1]	2	3	II	.....
6609.88[1]	8	8	II	.....
6616.68[3]	40	30	I	.....
6647.15[3]	4	6	II	.....
6656.82[3]	10	.....	VE	.....
6673.46[3]	8	.....	VE	.....
6673.82[3]	15	.....	VE	.....
6736.86[3]	4	3	II	.....
6747.2[3]	15	30	IIA	5?
6798.7[3]	30	60	IIA	5
6813.0[1]	4	.....	VE	5
6827.6[3]	8	.....	VE	5

λ	NOTES—PRASEODYMIUM
3415.722	Double in arc. Red comp. *Pr* II
3491.46	Blend carbon in arc
3551.405	Blend carbon in arc
3577.473	Masked by carbon in furnace
3615.188	May be blend of *Pr* I and *Pr* II
3621.088	*Pr* I line on violet edge
3715.619 3736.066 3736.574	Blend carbon in arc
3768.388	Strong *Gd* line at λ 3768.40
3830.716 3880.47	Blend carbon in arc
3913.525	Blend in arc with λ 3913.543
4027.667	Blend carbon in arc
4038.157	Blend in arc with λ 4038.189
4039.764	Blend carbon in arc
4062.504	Blend in arc with complex *Pr* II line
4189.346	Blend with edge of λ 4189.518
4223.210	Blend in arc with λ 4222.986
4225.544	Blend in arc with λ 4225.337
4290.512	Blend in arc with complex *Pr* II line
4303.508	Blend in arc with λ 4303.595
4328.912	Blend in arc with λ 4328.977
4387.587	*Gd* line at λ 4387.63
4392.087	*Gd* line at λ 4392.05
4395.816	Blend in arc with λ 4395.807
4403.600	Blend in arc with λ 4403.622
4404.707 4404.845	Blend in arc with complex *Pr* II line
5292.23	Blend in arc with preceding pair
5410.55	Furnace line probably *Pr* I. Blended in arc
5479.75	Red component stronger in furnace
5522.80	Partly *Pr* II. Red component complex
5524.14	Red component complex
5670.00	Blend *Pr* I and *Pr* II
5956.64	Blend *Pr* I and *Pr* II
6141.55	Blend *Pr* II with complex *Pr* I

In conclusion, I wish to express my obligation to Miss Brayton of the Computing Division, who has rendered much assistance in the reduction of measurements and in handling the tabular material.

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AN ANALYSIS OF THE FINE STRUCTURE OF THE D_3-LINE OF HELIUM

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ABSTRACT

The D_3-line of helium has been resolved into a triplet with the diffraction gratings of high resolving power and large dispersion in the high orders. *An analysis of the trace with the microphotometer* gives the ratio of intensity of 4.5:3:1 and the ratio of separation of 10.3:1. This result is completely verified by an investigation with an echelon spectrograph.

A new type of discharge tube, which is free from absorption and Stark effect and can be cooled with liquid air, has been designed to eliminate any chance of self-reversal.

A method of determining the relative intensities of unresolved or partially resolved components for a special case has been worked out.

Ornstein and H. C. Burger[1] have shown that the yellow helium line λ 5876 ($2P-3D$) is not a doublet of the $\pi-\delta$ type as described by Ruark, Foote, and Mohler,[2] and that the ratio of intensities is by no means 1:2 which is the well-known value for alkali doublets. It is also known that if Sommerfeld's alternation law holds for helium, its spectrum should consist not of doublets but only of "triplets," which term is used to include systems of simple lines that always occur conjointly with them. In 1926, the intensity relations were investigated by D. Burger[3] and both the sharp and the diffuse series were found to be more like systems of triplets with the intensity ratios of 5:3:1, but with the two strong components very close together. The results obtained from his experiments are given in Table I.

TABLE I

Term	Wave-length	Ratio of Intensities
$2P-3D$	5876	0.210
$2P-4D$	4472	0.145
$2P-5D$	4026	0.155
$2P-3S$	7066	0.145
$2P-4S$	4713	0.125
$2P-5S$	4120	0.130

[1] L. S. Ornstein and H. C. Burger, *Zeitschrift für Physik*, **26**, 57, 1924.

[2] Ruark, Foote, Mohler, *Journal of the Optical Society of America*, **8**, 17, 1924.

[3] D. Burger, *Zeitschrift für Physik*, **38**, 437, 1926.

The ratio of intensities indicates the relation expressed in percentage of the intensity of the *outer* component to that of the two close components. It has been suggested by Ornstein that the ratio of the abnormal intensities of the D_3-line may be due to the partial resolution of the two close components.

The theory according to Heisenberg[1] also requires a triplet structure. The theory predicts further that the separation of the levels $^3P_2$ and $^3P_1$ is about one-tenth that of $^3P_1$ and $^3P_0$.

The attempts to resolve the components by means of spectroscopic methods, however, have so far not been successful.[2] The only published result which shows a resolution of the D_3-line into a triplet was given by W. V. Houston,[3] but he was not certain whether or not his resolution was a mere reversal. The writer has attempted to reveal this superfine structure with large diffraction gratings and with an echelon. The results with both kinds of instruments give strong evidence of a triplet structure for the D_3-line under conditions free from absorption and Stark effect.

DIFFRACTION GRATINGS

The first source used was a Plücker tube with a one-millimeter capillary, filled with spectroscopically pure helium at a pressure of one millimeter of mercury. Light was taken perpendicular to the capillary to avoid any Stark effect. A thirty-foot Littrow spectrograph with a ten-inch grating having 12,000 lines to the inch was first employed. The theoretical resolving power in the sixth order was about 650,000. Pictures were taken with Eastman 40 plates dyed with pinacyanol chloride and also with Wratten panchromatic plates bathed in ammonia. An examination of the plates was made with a microphotometer and asymmetry in the strong component of the D_3-line was observed.

In the type of microphotometer employed, a projection lamp, a converging lens, and an adjustable slit are mounted in line, with the image of the filament of the lamp in good focus on the slit. After the light passes through the slit it is directed by a lens to a thermopile, which is connected to a sensitive galvanometer of the suspended

[1] W. Heisenberg, *Zeitschrift für Physik*, **39**, 499, 1926.

[2] MacNair and McCurdy, *Nature*, **117**, 159, 1926.

[3] W. V. Houston, *Proceedings National Academy of Science*, **13**, 91, 1927.

coil type. The plate to be examined is mounted immediately in front of the slit and is moved by an electrically driven clockwork. The microphotometer is self-registering, that is, the galvanometer deflections are recorded on sensitive paper on a rotating drum, which is controlled by the same clockwork that moves the plates across the slit. The relative rates of movement of the plates and the drum are arranged to give a convenient scale for the trace of a spectral line. The theory of the instrument will be given in a following section.

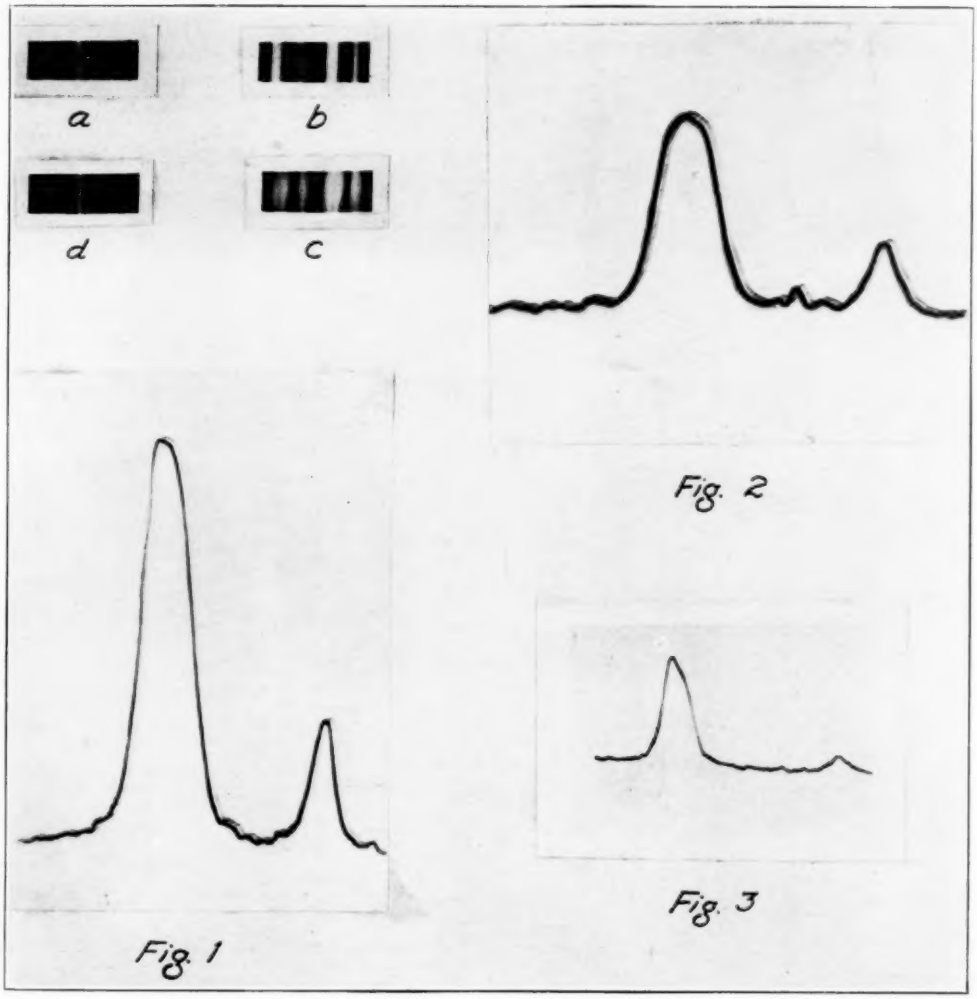
Next an eight-inch grating with 15,000 lines to the inch was used with the same thirty-foot Littrow mountings. The line was photographed in the fifth and sixth orders, where the theoretical resolving power was about 600,000 and 700,000 respectively. The dispersion in the fifth order was about 0.25 A. per millimeter. Three pictures were taken in the fifth order and two in the sixth. Microphotometric analysis of the pictures shows that the strong component is clearly a doublet, making the fine-structure of the D_3-line a triplet.

A microphotometric trace of one of the negatives is shown in Plate VII, Figure 1. The faint trace accompanying the main one is due to the reflected image from the walls of the lamp used to illuminate the galvanometer mirror. The symmetry of the outer component, the normal exposure of the negative used in making the trace, and the fact that the same form of curve is shown on traces of each of the negatives, all are in favor of the conclusion that this represents a true resolution of the line. A further proof for this conclusion is that when the slit of the microphotometer is made narrower, the doubling effect becomes even more striking. This is illustrated in Plate VII, Figure 2, which is a trace of the same negative as that of Figure 1, only with the slit of the microphotometer further narrowed down. The irregularities between the two close components and the outer components are not characteristic of the radiation.

THE ECHELON

This part of the work was undertaken with the hope that a prism and a twelve-foot lens would give a scale large enough to separate the two close components if resolved with the echelon. Two improvements were made on the source in order to make the lines sharper.

PLATE VII



STRUCTURE OF HELIUM LINE D_3

a, with Littrow; *b* and *c*, with echelon; *d*, with Paschen spectrograph
Microphotometric traces: Figs. 1 and 2, Littrow spectrograph; Fig. 3, with echelon

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First, the discharge tube was so designed that it could be operated at liquid-air temperature and that the self-reversal and Stark effects were the least probable. This was accomplished with tube II.

Secondly, a two-liter reservoir was connected to the discharge tube so that the tube would not get hard when the pressure of helium inside was very low. In previous work the tube had to be refilled often, due to the absorption by the electrodes and the walls of the tube. With the reservoir a much larger quantity of helium was fur-

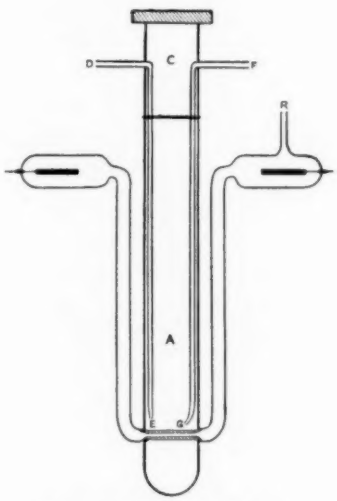

FIG. 4.—Discharge tube I

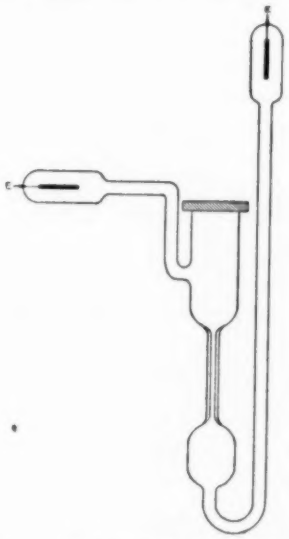

FIG. 5.—Discharge tube II

nished to the tube, so that the absorption would not decrease the pressure so very much. With the employment of this device, the life of the tubes was greatly lengthened.

The construction of the tube, which will be later referred to as tube I, is shown in the accompanying diagram (Fig. 4). The capillary of the discharge tube *B* is sealed in a glass vessel *A* which has a portable attachment *C*, sealed to it with wax. *C* is a glass tube with a window on the upper end for the transmission of light from the capillary, and with two outlets *DE* and *FG* which hang on either side of the capillary. In the diagram, *C* is turned through an angle of 90° for the convenience of drawing. The outlet *DE* leads to an oil pump, while *FG* with an extension tube goes into the liquid air

in a thermos bottle. As the pressure in vessel A is reduced by the pump, liquid air is siphoned in through FG and is sprayed over the capillary, which is thus kept cool and clear. The end E of the tube DE is just a little higher than the top of the capillary, so any excess of liquid air is automatically removed. The amount of flow through FG can be regulated very easily with a pinchcock on the lead to the pump. The capillary is always just below the surface of the liquid air; this will insure efficient cooling. In operation the major portion of the vessel A is also immersed in liquid air. Thus, with this arrangement, the light can be observed at right angles to the capillary at the liquid-air temperature with no sacrifice of intensity, and the evaporation of the liquid air at reduced pressure affords a very efficient means of removing the heat generated by the discharge.

The echelon used has thirty steps with $t=1.065$ centimeters, $s=\frac{1}{2}$ millimeter, giving a theoretical resolving power of about 300,000. With a twelve-foot lens the scale is about 0.13 A per millimeter. The instrument is mounted in a constant-temperature room, the same room as the thirty-foot Littrow. The echelon and the prism are mounted on a solid stone slab, and the photographic part on heavy cast-iron boxes. The collimating device was a tube mounted independently of the echelon and the boxes. The entire mounting was rigid and the instrument could be made to remain in adjustment indefinitely. A Cooper-Hewitt mercury lamp was used for the preliminary adjustment and all the main components of the green mercury line λ 5461 A could be seen very distinctly. The separation of the two close components on the long wave-length side of the main line indicated that the theoretical resolving power could be attained.

Pictures were taken with panchromatic films bathed in ammonia. In preparation for the exposure with tube I, the tube was mounted in front of the echelon spectrograph and light taken from the capillary inside vessel A was directed to the slit of the collimator with a right angle prism and a lens. The capillary was kept in good focus on the slit. Alignment of the source was made by visual observation. Before liquid air was introduced, it was necessary to remove all moisture in the system. With this precaution there was no difficulty due to frosting inside the vessel A.

When visual examination was made with liquid air running through the system as described above, asymmetry of the strong component of the D_3-line could be detected. Both the separations and intensities were about the same as predicted by Heisenberg.

The exposure took about fifteen hours, because the current density was very small. During the exposure close attention was paid to the removal from the glass window of the vessel C of water vapor condensed from the atmosphere. A microphotometer trace of the picture is shown in Plate VII, Figure 3. The operation of the discharge tube at low temperature brings out more clearly the intensity ratio of the two close components of the D_3-line.

ANALYSIS OF THE MICROPHOTOMETER TRACE

Assuming that the degree of blackening, or density, of a photographic plate with proper development is proportional to the intensity of the incident light and that all the components of the D_3-line have the same intensity distribution, the writer has calculated the relative intensities and separations of the components of the D_3-line.

The density of a photographic plate developed without potassium bromide is calculated from the opacity O, according to the following equation

$$D = A \log_{10} O$$

where the opacity is defined by the ratio of the amount of light transmitted by the unexposed portion of the plate to that transmitted by the exposed portion, that is,

$$O = T_0/T .$$

T_0 and T can be measured by means of a microphotometer. In the type of microphotometer used, the thermopile current is proportional to the amount of energy falling on the thermopile and the deflections of a galvanometer are proportional to the current. Hence, if u_0 and u are the galvanometer deflections for the unexposed and exposed portions of the plate respectively, we have

$$u_0/u = T_0/T$$

and

$$D = A \log_{10} u_0/u.$$

The microphotometric trace of a spectral line then is a function of the intensity distribution of the line. If the abscissas represent the distances perpendicular to the spectral line, the ordinates of the trace will represent the values of u_0-u for the corresponding abscissas.

To analyze the intensities and separation of the two close components of the D_3-triplet, the following procedure has been followed:

1. *Preparation of calibration curve.*—The ratio of densities of any two portions of the plate is given by the equation

$$D_2=D_1\frac{\log u_0-\log u_2}{\log u_0-\log u_1}$$

and letting the maximum density of the outer component of the D_3-triplet be unity, with u_1 equal to u_0 minus the maximum height of the trace of this outer component, we have

$$\log u=\log u_0-D(\log u_0-\log u_1).$$

The u's corresponding to different values of the D's are calculated. Since $u_0-u=h$ gives the actual height of the microphotometric trace for the density D, it is convenient to prepare an h, D calibration curve, which can readily convert heights to densities and vice versa. The calibration curve used in this analysis is based on Figure 1.

2. *Distribution of intensity in the triplet.*—Since the wave-lengths of the components of the triplets are so very close together, it is justifiable to assume that the intensity distribution of the radiations is the same as the distribution of density produced by the radiations on the photographic plate. With the calibration curve, the actual intensity distribution as shown in the photograph is deduced from the trace in Plate VII, Figure 1. Two distribution curves of the intensity have been obtained: one for the outer component and the other for the two close components. The former will be used as standard in the following calculation.

3. *Intensity and separation ratio of the components.*—St. John and Ware[1] have found experimentally that it is not possible to add two

[1] C. E. St. John and L. W. Ware, *Astrophysical Journal*, **44**, 15, 1916.

component microphotometric traces of intensities 3 and 4 to obtain the trace due to a spectral line which is supposed to be made up of these intensities. From the foregoing analysis one can see the theoretical reason for this: the microphotometer deflections are not additive. On the other hand, the densities are additive. With the outer component as the standard, distributions for spectral lines of intensities 2, $2\frac{1}{2}$, 3, $3\frac{1}{2}$, 4, $4\frac{1}{2}$, and 5 times as large as that of the standard are calculated. Then various combinations of these are tried until a combination is found which gives approximately the same distribution of intensities as that of the two close components, worked out according to the method outlined in the preceding section.

One cannot expect perfect agreement between these two intensity distributions: the one obtained by this method of combination and the other calculated from the microphotometer trace; because any slight error in the measurement of the distribution of the standard is multiplied four or five times in the calculated distribution for the two close components. But the method is quite critical. A small change, say a distance of $\frac{1}{2}$ mm, in the separation of the two components produces a remarkable change in the intensity-distribution of their resultant. As the microphotometer traces used in this calculation are enlarged photographically about five times the original trace, and the separation of the components are about thirty-five times as large as that on the photographic plate, the result is believed to be as accurate as can be expected from the experiment.

The choice of the combination is made on the following bases. In the first place, the resultant distribution should give the general form of the curve of the microphotometer, and, in the second place, it should give the same sort of distribution, especially between the maxima of the two close components. The latter has been considered the chief criterion. It has been found that with two components of intensities $4\frac{1}{2}$ and 3 both conditions are satisfied when the separation ratio of the triplet is 10.3:1. The echelon plate does not have strong enough intensity to apply to the theory of this section, but its microphotometer trace shows that the ratio of separation is very nearly the same.

With the assumption that the helium spectrum consists of "triplets," the intensities of the components of the D_3-line have

been calculated on the summation rule. As the transitions are $2^3P_2 - 3^3D_{123}$, $2^3P_1 - 3^3D_{12}$, and $2^3P_0 - 3^3D_1$, the theoretical intensity ratios are found to be 5:3:1 as against the experimental value of $4\frac{1}{2}:3:1$.[1]

Current methods for measuring intensity ratios have also been applied. First, there is the empirical rule that the intensities of two spectral lines are roughly proportional to the areas under their respective microphotometer curves. The curves of the two close components and the outer component of the D_3-triplet were traced on a sheet of co-ordinate paper, and the areas were compared in terms of the number of squares under each curve. It was a case of coincidence that the first time when this method was applied, the ratio came out exactly 8:1. This result is, however, confirmed by the average of a number of trials.

Secondly, there is the method of measuring the relative intensities of spectral lines from galvanometer deflections of the microphotometer, using the relation

$$D = \log_{10} T_0/T,$$

where T_0 and T have the same significance as before. Using our microphotometric trace, we found that the resultant intensity of the two close components was approximately five times that of the outer one. This result is in good agreement with D. Burger's measurement.

Therefore, expressing the intensities in terms of that of the outer component, we have found that by the method of comparing areas the *sum* of the intensities of the two close components is about 8, that by the method of comparing galvanometer deflections the *average* of their intensities is 5.22, and that by the analysis outlined in this section the sum of their intensities is $7\frac{1}{2}$ and their *individual* intensities are $4\frac{1}{2}$ and 3. These results are in agreement with the intensity measurement of Burger and in accordance with the theory of Heisenberg.

STUDY OF SELF-REVERSAL

Another type of discharge tube, which we shall refer to as tube II, was employed in the investigation. The design of the tube is shown in Figure 5. Like tube I, it was connected to a reservoir of two liters' capacity and was operated under the same conditions except that the light was taken along the capillary.

[1] W. V. Houston, *Proceedings of the National Academy of Science*, **13**, 91, 1927.

The tube was examined with the echelon spectrograph. When the body of the tube was not immersed in the liquid air, the stronger line of the so called "D_3-doublet" appeared to be broad with a very slight depression in intensity in the center. With the liquid air this broad line was divided into two lines. The sharpness of the division increased with the depth to which the tube was immersed in the liquid air. With the same setting of the spectrograph, which had been adjusted with the mercury arc, tube I and tube II were examined alternately for comparison. The structure of the D_3-line in the two cases was quite different. Tube II gave a much larger separation, as shown in Plate VII, *a*, which is a photograph of the D_3-line with the echelon.

The separation of the two lines of the strong component mentioned in the preceding paragraph seems also to be a function of the pressure of helium in the tube. When the pressure was about two millimeters of mercury, the separation was as large as one-fourth of the usual separation of the yellow doublet, but with lower pressure the separation reduced to only one-eighth of the separation of the doublet. As this discharge tube is similar to the one employed by W. V. Houston, the various tests made by him have been applied and his results have been in general verified. Therefore, as he has suspected, the appearance of the D_3-line in the type of discharge tube like tube II is due to unsymmetrical reversal. As shown in these experiments, the appearance of the lines depends on the temperature and density of the absorbing gas, and according to W. H. McCurdy, the D_3-line is one of the lines of helium which show strong reversal.[1] The conclusion is further confirmed by the fact that the outer component of the D_3-line also shows some traces of self-reversal.

EXPERIMENT WITH CONCAVE GRATING

An attempt has also been made to study the fine structure of the line with a twenty-one-foot concave grating, Rowland mounting. The spectrograph was changed into a Paschen mounting and the line was photographed in the third order. The relatively small dispersion of 0.85 A per millimeter makes it impossible to show the triplet structure of the line.

[1] W. H. McCurdy, *Philosophical Magazine*, S. 7, **2**, 529, 1926.

The result of the present investigation is in agreement with the measurement of intensity of Burger and is in accordance with the theory of Heisenberg.

It is hoped that the present investigation will contribute its part toward the removal of the helium spectrum from the anomalous position which the element now holds in spectroscopy. It is also hoped that the methods employed may be applicable to the study of other problems of fine-structure.

The writer takes great pleasure to express his thanks to Professor H. G. Gale and Assistant Professor G. S. Monk for their valuable advice and criticism and for the deep interest they have maintained throughout this investigation. Thanks are also due to other members of the staff for their assistance and encouragement and to Mr. Y. C. Chang for his help in adjusting the Littrow spectrograph.

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